A Summary of Current Program 4/1/65 *-*

and Preliminary Report of Progress

for 4/1/64 to 3/31/65

SOIL AND WATER CONSERVATION

RESEARCH DIVISION

of the

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

This progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between April 1, 1964, and March 31, 1965. Current agricultural research findings are also published in the monthly USDA publication, Agricultural Research. This progress report was compiled in the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

UNITED STATES DEPARTMENT OF AGRICULTURE

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INTRODUCTION

Research on farm resources must have two major objectives: (1) develop new or improved technology that will aid society as a whole in its interest in preserving and enhancing the value of the Nation's most valuable natural resources--soil and water--for future generations; and (2) develop new or improved technology in the efficient use of soil and water resources towards improving the net income of the individual farmer or rancher. Research endeavor on these resources should seek ways of attaining maximum compatibility between these two objectives.

As an illustration of the first objective, the Nation must be concerned over the fact that 1,500,000,000 cubic yards of erosion-produced sediment are deposited in the Nation's major reservoirs each year. This amount of sedimentation each year displaces water storage potential equivalent to the annual water supply needed for a city of 5,500,000 population.

With respect to the second objective, it is necessary to keep in mind that with all the vaunted affluence in the United States, the average annual income of farmers is only two-thirds that of the non-farm population. With the abundance of cropland that is evidently available in this country, research must seek ways of minimizing cost of production under extensive use of the land. Land use practices must be continually improved towards better efficiency in production while avoiding deterioration of the soil resource. Improved management of soil and water resources must integrate with highly mechanized operations, improved crop varieties, and protection from crop pests.

Past research has provided the impetus and know-how whereby American agriculture has achieved its present high efficiency. But the agriculture of tomorrow will be quite different from the agriculture of today. Again, the evolution will take place through the day-to-day work of imaginative, far-sighted researchers.

Developing sound technology for the conservation and utilization of soil and water resources on the Nation's farm and ranch lands is the prime responsibility of the Soil and Water Conservation Research Division, Agricultural Research Service, United States Department of Agriculture. It is a nationwide cooperative research program designed to provide specific information on hydrologic characteristics of agricultural watersheds relating to soil and water conservation, water yield, reduction of flood and sediment damages, including hydraulics of structures for conserving soil and water; nature and origin and control of sedimentation in reservoirs, streams and valleys; improved cultural practices for controlling soil erosion and water runoff, improvement of physical condition of soils, water storage and use by plants, drainage, irrigation, and salinity control; and relation of quality of plant materials grown under differing soil conditions to nutritional disorders in animals.

Virtually all of the Nation's water supply arrives as precipitation upon the land. Seventy percent of this supply is used in evaporation and transpiration directly from land. This 70 percent of the water budget is frequently ignored by water planners since it does not enter into the massed supply of rivers, lakes, and reservoirs that are of immediate interest to industrial and urban users. But water on the land is that which produces man's basic needs of food and fiber.

Agriculture has a vital interest in the 30 percent of the precipitation that enters into massed supply. Of the water diverted from rivers, reservoirs, and aquifers, agriculture now uses 40 percent. Most of this is for irrigation. But irrigation agriculture represents a highly consumptive use, whereas industrial and metropolitan uses of water are very low in consumptive use. Thus, irrigation agriculture uses 90 percent of our massed water supply that is consumptively used. Agricultural Research Service research in water conservation and irrigation is largely concerned with increasing basic knowledge and developing practices for increased water-use efficiency in agriculture.

The Water Resources Research Committee of the Federal Council for Science and Technology have given emphasis to the need for research on comparable water problems such as evapotranspiration, water behavior in soils, watershed protection, water yield improvement, conservation of water in agriculture, flood abatement, control of water on the land, use of water of impaired quality, erosion and sedimentation. These research needs are documented in a Report on "Water Resources Research" from the Senate Committee on Interior and Insular Affairs to the late President Kennedy.

The Soil and Water Conservation Research Division actively pursues many areas of soil and water research. The Division employs approximately 425 scientists, covering 17 widely varying disciplines. Its nationwide program is organized for convenience and efficiency into three main categories: (1) watershed engineering research; (2) water management research; and (3) soil management research. Information on these subjects is gathered through the activities of seven branches, organized by geographic regions. There is one Pioneering Research Laboratory--The Mineral Nutrition Laboratory--located at Beltsville, Maryland. Six national laboratories are incorporated into the various branches: U. S. Plant, Soil, and Nutrition Laboratory, Ithaca, New York; U. S. Sedimentation Laboratory, Oxford, Mississippi; U. S. Salinity Laboratory, Riverside, California; U. S. Water Conservation Laboratory, Tempe, Arizona; U. S. Soils Laboratory, and U. S. Hydrograph Laboratory, Beltsville, Maryland.

Also, the Division operates the following laboratories and research centers: Pomona Irrigation Laboratory, Pomona, California; Foothills Hydraulics Laboratory, Soil Phosphorus Laboratory, and The Nitrogen Laboratory, Fort Collins, Colorado; St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota; Stillwater Outdoor Hydraulic Laboratory, Stillwater, Oklahoma; Soil and Water Research Laboratory, Weslaco, Texas; Engineering Research Center, Fort Collins, Colorado; Southern Piedmont Conservation Research Center, Watkinsville, Georgia; Snake River Conservation Research Center, Twin Falls, Idaho; North Central Soil Conservation Research Center, Morris, Minnesota; Northern Plains Soil and Water Research Center, Sidney, Montana; Northern Great Plains Research Center, Mandan, North Dakota; Coastal Plains Soil and Water Conservation Research Center, Florence, South Carolina; and Southern Great Plains Research Center, Bushland, Texas.

Experimental Watersheds have been established and are in operation at Tucson, Arizona; Columbia, Missouri; Coshocton, Ohio; Boise, Idaho; Chickasha, Oklahoma; and Blacksburg, Virginia. All of these, plus approximately 90 field locations, contribute to the Division's research program.

Close cooperative relations are maintained with other Federal and State agencies, State agricultural experiment stations, education institutions, and industry.

Selected Examples of Accomplishments--1965

1. The structure of a ribonucleic acid determined.

A group of scientists from the U. S. Department of Agriculture and Cornell University, working at the U. S. Plant, Soil, and Nutrition Laboratory at Ithaca, New York, recently completed the determination of the structure of the alanine-acceptor ribonucleic acid (RNA). This is the first nucleic acid for which the complete structure is known. The alanine RNA is one of a group of nucleic acids known as transfer RNA's. They are the smallest biologically active nucleic acids. Their function is to carry activated amino acids to the site of protein synthesis. The determination of the structure of the alanine RNA is a major step toward a better understanding of the process of protein synthesis. Through disconveries of this type, some controls over the process of protein synthesis may eventually become possible. These controls may open up new routes of attack upon critical problems of nutrition, genetics, and medicine.

2. Farmers soon may irrigate by pushbutton or radio.

A new system to automate surface irrigation by remote radio control offers excellent possibilities to conserve irrigation water supplies by more efficient water application and, at the same time, reduce labor requirements. Field scale operations at Newell, South Dakota, and Fontenelle, Wyoming, have demonstrated conclusively that remote control of simple pneumatic valves is possible up to distances several miles from the farmstead. Two types of pneumatic valves have been developed and operated to apply irrigation water on level or nearly level basins, graded border strips or to furrows supplied either from open ditch or pipeline distribution systems. Basic components consist of: (1) The nylon-reinforced rubber pneumatic valve, (2) a three-way solenoid control valve, (3) a source of air pressure, and (4) a remote timer and transmitter. The system is a year or more away from the commercial market. Research continues on such things as comparative labor costs, comparative application efficiencies, "fail-safe" devices, transmission of signals by wires, as well as radio, and testing durability of components.

3. Hydraulic design of spillway trash racks.

Trash racks for pipe outlet spillways should be mounted outside the high velocity flow region, according to findings of the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma. Experiments on a full-size structure subjected to flows laden with stick trash have shown that moving a trash rack outward from the entrance crest a distance of only one-half of the diameter of the pipe outlet reduced the entrance loss coefficient from 2.2 to 1.5. Adding a skirt or side panel to the rack reduced this coefficient to 0.1. These findings will lead to the economic solution of the vexing problem experienced in some areas of the plugging of pipe spillways by trash and debris carried by the flow.

4. Application of evaporation retardants to water surfaces.

A new method was developed at the U. S. Water Conservation Laboratory, Tempe, Arizona, for continuously applying evaporation retardants to a water surface without using any mechanical devices. Discrete particles of long-chain alkanols, such as hexadecanol and octadecanol, were dispersed in a water-soluble matrix and were released as the matrix dissolved when placed in water. Several saccharides, including corn syrup and hydroxy-ethyl cellulose, proved satisfactory as matrix materials. The rate of producing evaporation-retarding films on the water surface was controlled by varying both the matrix-alkanol formulation and the area of material exposed to the water. A small vial of matrix-alkanol material, suspended from a float, reduced evaporation from a large outdoor tank by 40 percent for a two-week period. The soluble matrix provides an effective, inexpensive method of continuously applying evaporation-reducing films to small ponds and reservoirs for extended periods of time. The method has not been tested on large reservoirs.

5. Concrete blocks surpass riprap in controlling erosion along streambank.

An experimentally designed and placed streambank protection of cellular concrete blocks has successfully withstood floodflows for eight years on Buffalo Creek near East Aurora in western New York. The precast cell units are 16x24 inches and 4 inches thick, each with 24 holes 2x2 inches in size, and weigh only 83 pounds. The cellular concrete-block revetment was placed in a bend of the stream adjacent to a quarried stone riprap revetment containing a median stone of 17 inches with maximum stone weight of 3/4 ton. Only three of more than 600 blocks originally laid have been lost from flow conditions, whereas the performance of the 17-inch quarried stone riprap has been unsatisfactory. The two types of revetment would cost about the same under contract, $10 per square yard, if the concrete blocks were mass-produced and if quarried stone were available locally. Since 24-inch stone would be needed to provide streambank protection equal to the concrete blocks, the cellular concrete block revetment is extremely competitive with quarried stone riprap revetment.

6. Delayed fallow systems show promise as low-cost conservation practice for the Southern Great Plains.

Planting sorghum after wheat harvest and encouraging volunteer wheat after harvest holds promise as an improved conservation practice at lower costs for the Southern Great Plains, as shown by work at Bushland, Texas. Results show that only 10 to 20 percent of precipitation during the fallow period of a 2-year wheat-fallow system is stored in the soil for the next crop. Much of the 80 to 90 percent of moisture lost through evapotranspiration during fallow should be used for beneficial plant growth to provide soil cover, soil organic matter restoration, and production of grazing forage for livestock. Analysis of long-time records at 12 locations in the Great Plains from Bushland, Texas, to Mandan, North Dakota, show that wheat yields following delayed fallow equal those after clean fallow. Precipitation during the dalayed fallow should be used for sorghum and/or volunteer wheat growth to improve conservation and reduce farming costs.

7. New concepts about the erodibility of cohesive soils.

Contrary to presently accepted belief, a soil material does not have a single constant reisitance to erosion, but a range in values, according to findings at the USDA Sedimentation Laboratory, Oxford, Mississippi. For example, tests on a large number of cohesive soils show that maximum erosion rates for a given flow condition increased as the influence of wet aging--in soils where it induces stability--decreased. Soils that stabilized rapidly with wet-aging time exhibited maximum erosion rates at low antecedent water content and became less erodible as the antecedent water content approached near-saturation.

On the other hand, soils that stabilized quickly with wet-aging time exhibited maximum erosion rates at a higher antecedent water content; and further, the peak erosion rates were greater. Such information about the cohesive

properties of soils provides needed new insights for design of more effective measures for stream channel stabilization and erosion control.

8. Soil acidity affects adsorption of simazine.

Studies at the U. S. Soils Laboratory, Beltsville, Maryland, on the role of soil factors responsible for the adsorption of s-triazine herbicides indicate the amount of adsorption was closely related to the exchange of titratable acidity of the soil. Physical and chemical considerations have led to the conclusion that this adsorption is by proton association. The percentage adsorption was reciprocally related to the energy of exchange of hydrogen for simazine and indeptendent of the basic saturating cation. Simazine was adsorbed to a greater extent than atrazine from solutions of like concentrations.

9. Soil water storage important in reducing floodflow.

Analysis of one of the major storms of the 28-year record at the North Appalachian Experimental Watershed, Coshocton, Ohio, showed that soil water storage greatly reduced runoff, but that runoff could have been reduced below flooding had total soil moisture storage capacity of the upper 14 inches been used. Soil moisture observations prior to the storm showed that a total of 2.36 inches of water could be stored in the upper 14 inches--1.85 of which occurred in the top 7 inches of soil. Of the 2.50 inches of storm rainfall there was 0.69 inch of runoff and soil water storage increased 1.81 inches--practically the same as the storage space available in the top 7 inches of soil. Little of the available soil storage space below 7 inches was used in this severe storm period. If the storm water had been able to penetrate quickly into the pore space in the top 14 inches of soil, there would have been only 0.14 inch of runoff, and no flood. The study pointed out the need for developing soil management practices that permit the absorption of storm rainfall to greater soil depths and hence, decrease floodflow.

10. Deep tillage offers great promise in Texas Blacklands and on certain Palouse area soils.

Profile modifications of Houston Black clay to a depth of 2 feet by rototilling resulted in increased growth of both cotton and grain sorghum and control of cotton root rotat Temple, Texas. Improved plant growth may have resulted from reduced soil strength permitting greater root proliferation, better temperature-moisture relations, improved nutrient availability, or a combination of these factors. The absence of cotton root rot was probably due to desiccation of the soil after rototilling, but may have been due to improved temperature-moisture-aeration relations. Root proliferation to greater depths results in the plants using water from lower parts of the profile, thus increasing storage capacity and reducing runoff.

Plowing Freeman and Naff-Garfield soils of the Palouse wheatlands 3 feet deep increased water use by up to 1.2 inches and boosted wheat yields as much as

25 bushels per acre. These soils near Pullman, Washington, have dense B horizons of clay loam or silty clay texture which limit root penetration to depths of 20 inches or less. Deep plowing permitted roots to penetrate and extract water from greater depth, thus increasing the total water supply to the crop. Deep plowing where the B horizon was 30 inches or more from the surface did not measurably increase rooting depth, water extraction or yield.

11. Loss of pesticides in runoff and erosion.

Losses of the pesticide compound 2-4 dichlorophenoxyacetic acid (2-4D) from a preemergence application in washoff (runoff water and soil) from farmland were affected by the formulation of this material, the time interval before rainfall occurred after the material was applied to the soil, and soil moisture at the time of application. In tests using the bioassay method with cucumber roots at Watkinsville, Georgia, concentrations of 4.4 and 1.3 p.p.m. of the ester and amine forms, respectively, were measured in the washoff from an excessive-rate storm of 2-1/2 i.p.h. applied 1 hour after 2.2 lbs./acre of these materials were sprayed on bare soil. When the rain was continued for 2 hours the concentrations in the washoff during the last 30 minutes of the storm were 0.5 and 0.1 p.p.m., respectively. Losses of the amine form with test rains 48 and 96 hours after the material was applied were less than half the losses with the rain applied at 1 hour. Losses were somewhat greater in all cases where the materials were applied on wet soil than where they were applied on dry soil. This strongly implies that management procedures can be effective in reducing the movement of specific pesticides into surface runoff water.

12. Sensor for in-place measurement of soil salinity.

A sensor has been developed at the U. S. Salinity Laboratory, Riverside, California, for continuous *in situ* measurement of an index for gaging the salinity of the soil. The device measures the electrical conductivity of the soil solution in the film phase. The sensing element uses the operating principle described by Kemper and consists of metallic electrodes fixed in a small fine-grained ceramic block that is buried in soil. Improved design has reduced the response time and external field effects. The time required to complete 63 percent of the change in the equilibrium readings when a unit is transferred from one bulk solution to another is one to two hours. When tested in soil in the pressure membrane apparatus, about two-thirds of the units gave essentially no change of reading when the matric suction was changed from 0 to 5 bars. If stability of calibration and convenient temperature compensation can be attained, these sensors should be usable for following salinity status in farmers' fields. In addition, these units should expedite the refinement and use of soil-water management principles, such as the "leaching requirement".

13. Salinity effects on plant growth processes.

Studies on the suppression of plant growth by slainity at the U. S. Salinity Laboratory at Riverside, California, indicate that salinity reduces the rate of synthesis of DNA, RNA, and protein as well as the rate of cell enlargement and of cell division. In bean leaves, the duration of DNA synthesis, essential for cell division, is rigidly controlled by a regulatory mechanism or biological clock which appears to be outside the leaf itself. Salinity failed to delay this clock even though it markedly reduced the rate of DNA synthesis. The net result was less DNA snythesized, fewer cells produced, and, hence, smaller leaves on the salt-affected plants. The duration of cell enlargement in bean leaves is evidently controlled by a separate regulatory system, although cell enlargement and cell division were coordinated as long as the latter occurred. Chloride salinity prolonged cell enlargement, especially the elongation of palisade cells, and the accompanying synthesis of DNA and protein. Palisade cells in the affected leaves grew to nearly twice their normal length. This phenomenon probably accounts for the greater thickness and succulence of leaves often found under saline conditions.

14. Automatic measurement of snow water equivalent.

The pressure pillow method for measuring snow water equivalent, first investigated as to practicability by the University of Idaho under an ARS research contract, is undergoing further testing and evaluation on the Reynolds Creek and Sleepers River Experimental Watersheds in Idaho and Vermont, and also by various other Federal and State agencies, universities, and private institutions. The pillow is made of synthetic rubber, 12 feet in diameter, and filled with a mixture of methanol and water. It operates on the principle that pressure exerted by a given amount of snow on the pillow is directly related to the water content of the snow. Various possibilities exist for converting these pressure changes to water equivalents, including telemetering of results from remote inaccessible locations. Approximately 100 such pillows were in operation on a trial basis in the winter of 1964-65. Experiences to date are promising, and while it is not yet known that the pillows will operate successfully in all environments, it does appear that the pressure pillow system has the potential of reducing time-consuming manual measurements of snow depths and, at the same time, providing information from remote areas which otherwise could not be sampled.

15. Statistical method for estimating the maximum rainfall.

A method was developed by the USDA Hydrograph Laboratory for estimating both the probable maximum rainfall and lesser rainfalls on a frequency basis for durations from 5 minutes to 24 hours. The procedure requires the use of several graphs and two statistics which can be computed from generally available tabular or graphical data. The probable maximum rainfall, which is defined as the largest rainfall that is ever likely to occur at a

specific location for a particular duration, is used in the design of hydraulic structures for agricultural watersheds when the risk of failure must be minimized. Frequency statistics are used for design criteria when a calculated risk of structure failure can be accepted.

16. Sulfur deficiency in the Great Plains.

Sulfur deficiency must be considered in management of some dryland soils and crop residues in the Great Plains. Studies at Fort Collins, Colorado, showed that with adequate nitrogen and phosphorus, the decomposition rate of straw in soils low in sulfates depended on the sulfur content of the straw. Incubation studies showed that for a maximum rate of straw decomposition, the sulfur content of the straw had to exceed about 0.15 percent, unless fertilizer sulfur was added. Growth of winter wheat on a nitrogen- and phosphorus-fertilized soil in greenhouse pots was governed by the S content of straw mixed in the soil. Straws with less than 0.15 percent sulfur added to soil depressed wheat growth, but straws with a higher sulfur content increased yields, compared to the no-straw treatment. When sulfur was added along with nitrogen and phosphorus, the sulfur content of straw had no significant effect on wheat growth.

AREA 1: SEDIMENTATION PROCESSES IN RELATION TO WATERSHED DEVELOPMENT AND PROTECTION

Problem. Most sediment problems are associated with the unwanted deposition of eroded material in reservoirs, harbors, stream channels, streets and highways, or on floodplain lands. In addition to these deposition problems, sediment in streams damages fish, wildlife, and recreation values. It must be removed, often at considerable cost, from domestic and industrial water supplies. Sediment in transport, the imbalance of the sediment load in streamflow because of alterations or impoundments in channel systems, and even erosion control practices in tributary watersheds, can also create sediment problems of major proportions. In many parts of the country abatement of sediment damages is one of the primary justifications for watershed protection and development programs.

The processes of sedimentation are complex, but an understanding of these processes and the factors controlling them is essential for the development of practices and programs for solution of sediment problems. The relation between sediment load, streamflow, land use and watershed characteristics must be clarified through research. Improved criteria are also needed for computing the bedload movement of sand, gravel and other coarse debris; for predicting the rates of silting, the trap efficiency, and the distribution of sediment in flood water detention reservoirs; and for describing the morphology of stream channel systems having beds and banks of alluvial or cohesive soil materials.

This research seeks new and improved criteria for evaluating various sedimentation processes, for identifying sediment sources, and for developing methods for sediment control and stream channel stabilization.

USDA AND COOPERATIVE PROGRAM

The Division carries on a continuing long-term program of both basic and applied studies of sedimentation processes, involving hydraulic and agricultural engineers, soil scientists, soil physicists, geologists, chemists, and botanists, for the purpose of developing and proving new information useful in the solution of various sediment and stream channel problems. Concentrated research in all aspects of sedimentation is carried out at the USDA Sedimentation Laboratory, Oxford, Mississippi, where over half of the Division's professional personnel doing sedimentation research are headquartered. At other locations, attention can generally be given only to the most critical problem of the region.

All of the studies are cooperative with the respective State Agricultural Experiment Stations and, in addition, cooperation is maintained with the Illinois State Water Survey, University of Mississippi, Oklahoma State University, and the University of Oklahoma Research Institute.

A total of 32.0 professional man-years was devoted to research in this area in the 1964 reporting period. Of this number, 16.7 man-years were devoted to studies of sediment sources and yields from agricultural watersheds; 1.6 to rates and processes of reservoir silting; 4.7 to mechanics of sediment entrainment, transportation and deposition; and 9.0 to stream channel morphology and means and measures for channel stabilization.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in studies of the sedimentation process. These studies seek a better understanding of the scientific principles involved in sediment movement and deposition. Efforts are also being made to determine the sources and yield of sediment from watersheds.

The total research effort in sedimentation problems at the State experiment stations is 2.0 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Sediment Sources and Yields from Agricultural Watersheds

1. Sediment sources. There are indications that hardpans in the soil profiles influence runoff and soil loss from the research plots at the North Mississippi Branch Experiment Station, near Holly Springs, Mississippi. Water outcropping into some of the plots has been observed and erratic runoff measurements on other plots indicate the possibility of water outcropping. The potential effects of such hardpans were unsuspected when the experiments were designed and the plots selected, indicating still another variable that must be considered in establishing and evaluating factors affecting rates of erosion and sediment sources.(SWC 1-bE1)

A Grenada soil was found to be increasingly erodible with depth to a depth of 20 inches in the soil profile. This was determined by subjecting soil samples to standardized hydraulic tests. The reason for this increase is not yet known; but it suggests that, for this soil, the erosion rate increases as cumulative erosion increases. It also suggests a possible reason for variations in sediment production from otherwise similar experimental areas at the North Mississippi Branch Agricultural Experiment Station. (SWC 1-bE1)

Evaluation of the dual probe method of measuring sediment density was continued at the Sedimentation Laboratory, Oxford, Mississippi, with emphasis on the measurement of soil moisture as a function of soil density. The attenuation of gamma rays from Cs-137 sources has proven of practical use in measuring changes in soil moisture content. Measurements can be at increments of 1 inch. The addition of a pulse height analyzer to the detection system has improved the accuracy and simplified the measurement of gamma-ray flux density. It is anticipated that such work will lead to methods of evaluating antecedent surface soil moisture as a factor in sediment production. (SWC 1-bE1)

Major revisions to the counting mechanism in the radiocarbon dating apparatus at the Sedimentation Laboratory and isolation of the equipment from all but minor electrically induced interference resulted in an improved system for carbon dating. The counting rate is now 21.1 counts per minute for contemporary carbon with a background rate of 2.3 counts per minute. Forty samples were analyzed; some for checks on the chemical and counting procedures and some for dating sediment deposits. (SWC 1-bE4)

Studies at Hastings, Nebraska, to determine volumes of gross erosion on agricultural lands, using 5-foot contour interval maps developed from high-level uncontrolled aerial photographs, gave negative results, but more accurate maps show promise. One-foot contour maps have been compiled from controlled low-level aerial photos and are being used in studies of erosion on a 450-acre area. (SWC1-d2)

At Chickasha, Oklahoma, field measurements of sediment transport in the mainstem of the Washita River and selected tributaries showed denudation rates and sediment sources to be related apparently to the lithology of the watershed. Average watershed denudation rates were calculated from the three years of sediment transport data and expressed in inches of soil removed per 1,000 years. Five watersheds with sandstone as the principal lithology had denudation rates ranging from 0.88 to 3.71 inches per 1,000 years. In the sandstone and shale areas, denudation rates were higher, ranging from 8.51 to 29.03 inches per 1,000 years with one exception having a rate of but 0.81 inches. The broad range, both within and among the several physiographic areas, highlights the necessity of providing improved procedures for estimating the amounts of sediment delivered from the various areas. (SWC 1-e1)

A reconnaissance of the geologic sediments and stratigraphy of the Southwest Experimental Watersheds was completed in the past year and detailed geomorphic surveys were initiated on the Walnut Gulch Watershed, near Tombstone, Arizona. This detailed study is proceeding first in the Lucky Hills area for correlation with intensive sediment production measurements now being made there. Information on the existing land forms is expected to indicate past erosional processes and relate to present sediment production. (SWC 1-g1)

A study was completed of the degree of rounding of quartz granules in valley deposits on the Walnut Gulch Experimental Watershed in relation to their distance of transport. It is considered that such information will be helpful, along with mineralogical studies, in identifying sediment source areas and estimating rates of transport for predicting sediment yields of watersheds. (SWC 1-g1)

Measurements of microtopographic changes were initiated on unit-source watersheds in the Lucky Hills area, near Tombstone, Arizona. Maximum erosion and deposition measured along a ridge line (drainage boundary) following the 1964 runoff season were 0.02 and 0.03 foot, respectively, with no general change in the topography. However, similar measurements in minor drainage channels of the area showed general erosion in their upper reaches. Total sediments removed from these watersheds are being determined also by survey of deposits above the runoff measuring stations and by analyses of runoff samples. (SWC 1-g1)

2. Roadside sources of sediment. At Cartersville, Georgia, studies to determine sediment delivery rates from selected bare roadbanks in the Southern Piedmont revealed that rates on Cecil soils were highly correlated with EI (rainfall energy-intensity) values. However, other climatic factors, still to be evaluated, significantly affected these rates. For example, from 5-year averages, only 216 EI units were required to pass a sediment module of 1 ton per acre through the sampler during the first quarter of the years, whereas, 1,062, 1,626, and 625 EI units were needed to deliver this same amount for the second, third, and fourth quarter, respectively. In a comparison of sediment production from vegetated and nonvegetated experimental roadside areas, it was found that the average loss from vegetated plots was only 8 percent of that from nonvegetated plots. Most of the sediment losses from the vegetated plots were derived from scouring of the unprotected road ditches. (SWC 1-b1)

In investigations to find the most suitable method for measuring the amount of vegetative cover on roadbanks in the Southern Piedmont, it was found that a point-count index evaluation was closely correlated with vegetation yields obtained from harvested samples. The equation $Y=632X-58$, where Y is the total number of "hits" made on the plant cover and X is the dry-weight yield in tons/acre, gave a correlation coefficient, r, of 0.995. The point-count measuring device was 5 feet long with 20 equally spaced pins, or prongs, each 18 inches long. Plant "hits" were measured at four random locations in each plot. On the other hand, the visual rating method of estimating percentage of cover appears subject to bias. All observers tended to underestimate the stands of poor cover. However, such ratings may still be useful in estimating the degree of erosion protection offered by vegetation. For instance, visual cover ratings of about 90 percent corresponded to a yield of about 1.65 tons/acre with a point count of 1,000, whereas, 100 percent visual ratings gave a yield of 2.5 tons/acre and upward with a point count of 1,500 or above. Future tests on sediment production from roadbanks may show that 2.5 tons/acre of vegetative cover

will give almost complete erosion control with the species that were used. Plant covers studied were mixtures of Pensacola bahiagrass and bermudagrass, sericea lespedeza and lovegrass, Kentucky fescuegrass and Italian ryegrass, and crownvetch and Abruzzi rye. (SWC 1-b1)

The effectiveness of several mulching treatments in reducing runoff and soil loss on newly prepared and seeded highway backslopes of 2½:1 in Oconee and Peach Counties, Georgia, was evaluated using the rainfall simulator. Test storms were applied at the rate of 2½ iph in two 30-minute increments immediately after planting. The total 1-hour storm has an occurrence probability of 10 percent (10-year frequency). A grain-straw mulch surface-applied at the rate of 2 tons/acre was the most effective treatment wherein runoff and soil loss were 1 inch and 8 tons/acre, respectively. The next best treatments were suface-applied grain-straw mulch (2 tons/acre) specked with hot asphalt (AE-5) as a sticking agent, and grain-straw mulch (2 tons/acre) pressed into the prepared soil by a blunt-edged roller at 8-inch intervals along the contour (whisker dams). These treatments permitted 1 inch of runoff and 12 and 13 tons/acre of soil loss, respectively. Unmulched areas lost 1.4 inches of runoff and 116 tons/acre of soil. (SWC 1-b1)

3. Sediment yields. A device for sampling total sediment load in streamflow at overfall structures has been designed and installed by the Sedimentation Laboratory at a total-load site in the Pigeon Roost Creek Watershed, near Holly Springs, Mississippi. This device is mounted on a steel bar-joist bridge in a manner that permits sampling at each of several predetermined verticals in the cross section. It is constructed of aluminum, with the exception of a short length of 2-inch-diameter iron pipe and a 4-foot length of airplane wing strut to which a standard US D-48 sampler is attached. The entire structure weighs approximately 200 pounds. The up-and-down motion of the actual sampling mechanism, through the depth of flow, is controlled by a vertical mounted carriage which is attached to a standard type-A depth sounding reel. The wheel bearings which support the structure on the top railing of the footbridge permit movement from one end of the footbridge to the other with very little effort. The position of the D-48 sampler nozzle with respect to the downstream top edge of the overfall plate is regulated by a depth gage attached in part to the vertical carriage and supporting guide member. In order for the operator to know when he has lowered the sampler through the total depth of flow, the depth gage is preset for each selected vertical in the cross section. The exact position and elevation of the sampler nozzle with respect to the overfall plate is checked after each storm runoff event and any necessary adjustments are made at that time. The performance of this sampling device will be evaluated by comparison of concentrations with conventional techniques of sampling. (SWC1-bE1)

A 200-pound P-63 sampler is in use in the Pigeon Roost Creek Watershed to improve the quality of suspended sediment samples collected during high stages and velocities. This sampler is equipped with a two-position rotary valve that permits the collection of depth-integrated samples and also samples at selected points in the vertical. The weight of the P-63 sampler has necessitated the use of a power-operated crane for lowering and raising the sampler through the depth of flow. A battery-operated power crane, similar in design to one used by the U. S. Geological Survey, has been constructed by the Sedimentation Laboratory and mounted on a 3/4-ton truck. Depth-integrated samples collected with the P-63 and D-49 samplers will be compared with samples collected by presently accepted methods. (SWC 1-bE1)

Work was initiated at the Sedimentation Laboratory toward the design and development of a traveling slot runoff sampler to be used in conjunction with a Parshall flume or some other runoff measuring device to take storm integrated samples for sediment concentration determinations. The traveling slot sampler, in its present state of development, is approximately 3 feet high x 1.5 feet wide x 3 inches thick. It was fabricated from 3/16-inch aluminum plate and the entire front edge is tapered and beveled from 3 inches to a 3/16-inch slot. The sample is collected through the slot and routed out through a discharge spout in the bottom into a stationary collection tank. When in operation the sampler traverses back and forth through the flow nappe with a "pause period" on each side. Stationary fiber brushes were placed on each side of the flume to remove trash from the slot as it passes by. It is chain driven and powered by a 1/4-hp. electric motor. Two 12-volt batteries, connected in series, are presently being used as a power source. Under normal conditions it will operate for a period of 8 to 10 hours on fully charged batteries. The sampler was tested, rather extensively, in the laboratory with a 6-inch-wide flume. Mechanically, it performed satisfactorily, but the sampling rate did not remain constant for all discharges. As the equivalent discharge per foot of width was increased from about 0.1 to 8.0 c.f.s. the sampling rate decreased from about 0.24 to 0.18 percent. The computed sampling rate for these tests was about 0.2 percent. Although the capacity of the sampler had not been reached, laboratory facilities at the time were inadequate for testing at higher discharges. The reason for the varying sampling rate is unknown at this time. For most situations the spread in values would not appear to be great enough to prohibit the use of the sampler for sediment measurement within the range of discharges tested. Errors induced by the varying sampling rate would depend, to a large extent, upon the sediment concentration of runoff. (SWC 1-bE1)

The traveling slot runoff sampler is now being field tested below a 2-foot Parshall flume on a 1.6-acre cultivated (corn) watershed at the North Mississippi Branch Agricultural Experiment Station, near Holly Springs, Mississippi. There have been problems associated with the field installation but the sampler has performed satisfactorily during several runoff events since it was installed in December. Anticipated trash problems have not yet

developed. Some possible improvements in the design have already been noted. Most likely, others will become apparent as the field tests continue.(SWC 1-bE1).

The Sedimentation Laboratory continued its active cooperation with the Inter-Agency Sedimentation Subcommittee in their encouragement of the Atomic Energy Commission in sponsoring work with Parametrics, Inc., of Waltham, Massachusetts, for the development of a nuclear device for sensing and recording the concentrations of suspended sediments in flowing water. In September a prototype model was received from Parametrics and tested in the laboratory and in the field with varying concentrations of suspended sediment. A revised prototype is scheduled for further testing in 1965. (SWC 1-bE1)

Sediment yield studies were started on 73- and 148-acre watersheds in corn in the Iowa and Missouri Deep Loess Hills Land Resource Areas near Traynor, Iowa. For the period February through December 1964, sediment loads from contour-tilled corn watersheds were in excess of 30 tons per acre. Gully erosion comprised a large part of the total sediment yield, but records are not yet sufficient for determining the relative sediment sources. (SWC 1-c1)

Studies of the effect of conservation practices on sediment yield were continued on two watersheds, each in the 400-acre size category, one with and one without conservation treatments, in the Upper Beaver Creek Watershed, near Rosemont, Nebraska. Data collected since initiation of the studies in 1957 were analyzed during the year. Some of the more significant findings from this analysis include: (1) A geomorphic evaluation of the two watersheds showed them to be similar in aspect, soils, geology and land form features. (2) Land treatment measures reduced sediment yield in excess of 50 percent when compared with an untreated area. The long-time effect of land treatment measures could not be firmly established, however, because of interference by reservoir installations. (3) Each watershed required separate sediment rating curves for rising and falling stages. For a given rate of runoff, the sediment concentration by weight averaged 2 or 3 times greater on the rising stages than on the falling stages. And on selected events, this difference was a much as 10 times greater. (4) The sediment yields from these complex watersheds are high, 8.4 and 4.5 tons/acre/year from the conventionally and conservation-farmed areas, respectively, but they do conform to other data for loessial soils regions. (5) Suspended sediment samples taken automatically, using the rising stage samplers, compared favorably with those taken manually, using the US DH-48 samplers. The differences in concentration values were considered insignificant. (6) Sediment concentrations during snowmelt periods were lower and more erratic than those during the growing season, and no correlation could be established between rates of runoff and sediment yields. (SWC 1-d2)

Sediment concentrations obtained from single-stage samplers appear to be consistently higher than those obtained with the US DH-48 hand sampler, at Flume No. 1 on the Walnut Gulch Experimental Watershed, Tombstone, Arizona. For two runoff events last year, the average concentrations of samples obtained by the single-stage samplers were 4.16 and 4.44 percent by weight as compared with 2.26 and 3.01 percent by weight of samples obtained by the hand sampler. Further studies are needed to establish the dependability of the single-stage samplers for use on this watershed. (SWC 1-g1)

Almost 400 depth-integrated and single-stage suspended sediment samples were collected on the Walnut Gulch Experimental Watershed in the 1964 runoff season, in the main channel at Station 6 (37 sq.mi.) and Station 1 (58 sq.mi.). A number of samples were collected at Station 6 with an experimental pumping sampler, collecting at 5-minute intervals. Analyses of these samples, collected at one depth, near one bank, will be compared with those of depth-integrated samples (manually collected) from near the center of the stream. (SWC 1-g1)

Analyses of samples collected in 1963 and 1964 at Station 6 on the Walnut Gulch Experimental Watershed have shown such scatter of concentrations as to, so far, preclude development of a "sediment rating curve". Sand concentrations have been less on the rising side of the hydrograph than on the falling side. Suspended sediment loads measured at this station have ranged from around 0.6 percent to about 4.0 percent of the flow, averaging in the order of 1.0 percent. (SWC 1-g1)

In one flow on Walnut Gulch Experimental Watershed, mainly from an area having had no recent heavy runoff, a peak sediment discharge rate was indicated to be about 8 tons/second, corresponding to a peak flow of a little less than 8,000 c.f.s., and a peak sediment concentration of approximately 4 percent. Sediment concentrations later in the runoff season were lower and concentrations varied over a wider range during the flows, about twice as high in the forepart of the flow as near the end. The suspended sediment concentrations appeared to be generally inversely more related to the elapsed time from the beginning of the flow than to flow rates. (SWC 1-g1)

Sediment source and transport studies initiated on the Calleguas Creek Watershed in the southern California coastal area have presented unusual opportunity for measuring total sediment loads. The measurements utilize several existing channel grade control structures. The structures were modified slightly to provide a free-falling nappe under which two types of bedload samplers have been tried. The samplers expose a nest of graduated sieves to the flow, permitting the water and suspended materials to flow through, but retaining the coarse-sediment fractions. One type, using standard 8-inch-diameter laboratory sieves and having a vertical slot intake, appears most promising for obtaining breadth-integrated bedload samples, by horizontally traversing the flow over the drop structures where discharge rates are low. (SWC 1-g1)

A substantial number of both bedload and suspended samples were obtained in two flow periods in the past year from several small tributaries in the headwaters areas of the Calleguas Watershed, which represent major sediment source areas. The bedload fraction was larger than anticipated, in some cases exceeding 30 percent of the total load for discharges less than 5 c.f.s. Total sediment concentrations ranged from about 1.5 to 3.5 percent, with a mean of approximately 2.0 percent. (SWC 1-g1)

B. Rates and Processes of Reservoir Silting

Working with a gamma probe in water depths up to 65 feet and obtaining penetrations of reservoir sediment deposits up to 10 feet, representatives of the Sedimentation Laboratory found that the dry densities of deposits in Lake Guayabal, Puerto Rico, ranged from about 25 pounds/cubic ft. to 50 pounds/cubic ft. The annual rate of sedimentation between 1950 and 1964 was determined to be 3.07 acre-feet/square mile of the drainage area as compared with an average of 3.69 acre-feet/square mile for the period 1914 to 1950. (SWC 1-bE1)

The calibration curve for the gamma (single) probe, computed with sediments derived from the Southern Mississippi Valley Silty Uplands in north Mississippi, was found to be applicable to sediments derived from soils in the Texas Blackland Prairie Land Resource Area. However, densities of reservoir sediments derived from the Texas Blackland Prairie soils were less than those encountered in the Southern Mississippi Valley, probably as a result of a high content of expanding lattice-type clay in the Texas soils. Reservoir sediments in Lake Guayabal, Puerto Rico, were comparable in density to those observed in the Southern Coastal Plain. (SWC 1-bE1)

Hydrologic records were continued for five ponds (tanks) on the Walnut Gulch Experimental Watershed, near Tombstone, Arizona, and two on the Alamogordo Creek Watershed, near Santa Rosa, New Mexico. No new data were compiled in the past year on sediment deposits in any of the ponds. Conditional plans completed during the year for future development of the Alamogordo Creek Watershed, call for study of several additional stock tanks, including measuring their sediment deposits and trap efficiencies. Research in this area is basic to the design of water storage and flood detention reservoirs, to determine the amount of sediment storage that will be needed. It is essential also to the design of debris-control structures for protection of roads, water supply canals, and lower-lying farm and urban areas. Effort in this line of investigation is at present nominal and incidental to other work. Its importance warrants considerably increased effort. (SWC 1-g3)

C. Mechanics of Sediment Entrainment, Transportation and Deposition

1. Bedload transport. The first significant movement of coarse-textured bed material since the establishment of the research site on the Little Hoosic River, near Berlin, New York, occurred on March 5, 1964, when a peak flow of 250 c.f.s. was measured. About 260 cubic yards of bedload material was trapped in the debris basin. When the hydraulic characteristics of the peak flowwere used in the Meyer-Peter formula, it was found that the weighted mean particle size in the streambed was so large that no bedload transport should have taken place under the observed conditions. However, when the mean size of the bank material was substituted for that of the bedload material, then the Meyer-Peter formula produced almost exactly the amount of material deposited in the debris basin. While this result can be attributed to a coincidence, it does emphasize that how and where to measure the mean size of the particles to be moved are important parts of the problem of predicting bedload transport. One approach planned to meet this need is to paint the bed material across one section with an invisible paint which can be seen under ultraviolet light. This approach should make it possible to determine which flows cause incipient motion and dispersion of bed material downstream. (SWC1-a1)

Previous model studies of forces on streambed particles at the Sedimentation Laboratory have shown the general order of magnitude for the drag coefficients due to channel-flow forces that act on a single spherical particle. This year progress was made in refining the transducer design and sensitivity for the large-scale Reynolds' model used in these tests. It is hoped that the refined model will yield data that can be used to better evaluate forces acting on an individual sediment particle in the streamflow boundary layer. (SWC 1-bE3)

Investigations to relate the dimensional properties of channel bed configurations to channel roughness parameters were continued in flume studies at the Sedimentation Laboratory. The experiment showed that dunes were generated on the sandbed at moderate flow rates, and as flow rates were increased the dunes became longer with no significant increase in amplitude. However, with increased discharge, small antidunes formed on the tops of the long dunes in a transitional phase that culminated in a train of stable antidunes at high discharge. Assuming a gradual transition between a dune-dominated and an antidune-dominated channel bed, an inflection point should exist where the head losses due to stable antidunes being generated on the dune backs become more significant than the head losses due to the dunes themselves. Data on elevations of the flumebed indicated that depth auto-correlation functions could be used to obtain typical boundary configuration lengths due to flow in sand-bed channels. The relative configuration lengths thus obtained reached maximum values at a Reynolds' number of around 700,000. This corresponds, at least in these experiments, to the Reynolds' number at which the inflection point of the channel resistance function occurs. This may be the point at which the head losses in the channel are caused more by the antidunes than by the dunes. (SWC 1-bE3)

At Chickasha, Oklahoma, studies of the streambed material of the Washita River and tributaries showed considerable change in size gradation during a storm flow. At the Verden station, material finer than 0.062 mm. increased 15 percent and 0.250 mm. sand increased 47 percent. This is significant in that computation of unmeasured load is based on bed material characteristics. Determination of bed material gradation based on a single sample, therefore, could lead to considerable error in the estimate of unmeasured load. (SWC 1-e1)

D. Stream Channel Morphology and Means and Measures for Channel Stabilization

1. Channel stabilization. The experimentally designed and placed stream-bank protection of cellular concrete blocks has successfully withstood floodflows for eight years on Buffalo Creek near East Aurora in western New York. The precast cell units are 16 x 24 inches and 4 inches thick, each with 24 holes 2 x 2 inches in size, and each weighing 83 pounds. They were placed close together on a carefully sloped bank at a bend in the creek that is subject to erosive stream action. Holes in the blocks were filled with sand and gravel of varying sizes and later supported some vegetative growth. Part of the bend was protected by quarried riprap stone of 17-inch median size, with a maximum stone weight of 3/4 ton. The revetment has been subjected to estimated shear stresses of 3.2 lbs./sq. ft. at its surface and to the impact of massive ice floes. Only three of more than 600 blocks originally laid have been lost from flow conditions. In contrast to this success, the quarried stone riprap in adjacent areas has been unable to withstand these forces. The cost of installing the cellular blocks in 1956 was only slightly higher than the stone riprap which was readily available in the vicinity of the experimental installation. (SWC 1-a1)

The maintenance costs of the experimental cellular revetment described above have been low, but the loss of a few blocks emphasizes that this can only be achieved where the outside edges of the revetment are fully protected and the quality of the concrete blocks is excellent. Because the quality of the original concrete blocks was only fair, several blocks were replaced after being damaged during the past winter. New blocks of a better quality were obtained to replace the damaged ones and to extend the revetment 32 inches higher on the bank. Care was taken to grout all the new blocks together and to blend the new rows into the bank so there would be no sharp projections to catch ice cakes and floating debris. Frequent destruction of the adjacent portions of the quarried stone revetments points out the necessity for designing the revetments for the especially high velocities and shear stresses which result from flood waters accelerating over a relatively smooth surface. (SWC 1-a1)

Studies of effects of stabilization structures on channel gradients and cross sections are underway on the Calleguas Creek Watershed in Ventura County, California. An initial survey was completed of an 1,800-foot channel reach in which there are five grade "drop" structures.

Thirteen cross sections were monumented, for resurvey following major runoff events. There are numerous additional channel reaches in this area, with varying runoff and sediment regimes and varying channel hydraulic conditions, which may later be included in this study. Original grades and channel geometry can be determined also, either from existing construction records or by probing the sediment deposits which have accrued since the construction. (SWC 1-g2)

2. Channel morphology. Continuing study of stream channel geometry of Buffalo Creek, near East Aurora, New York, combined with data obtained by Chatley on the Whangpo River in China and by Ippen and Drinker of Massachusetts Institute of Technology, has produced a formula which can be used as a first approximation of the minimum depths to which riprap should be placed in channel bends. The formula is:

$$\frac{Dm}{\bar{D}} = 1.18 \left(1+4 \frac{\theta W}{\pi R}\right)$$

where Dm is maximum depth in a bend, $\bar{D}$ is mean depth in that flow cross-section, θ is included angle of the bend, W is top width of the bend, R is radius of the outer bank, and π is 3.14. (SWC 1-a1)

Surveys and observations have been made of stream channel improvements by the Soil Conservation Service on the Pequest River in northern New Jersey since 1954 to establish information on channel adjustments with time and in response to known flow conditions. The improvements consisted of straightening and enlarging the channel, removing vegetation from the banks, and sloping the banks. No major changes have occurred within the 10-year period. Since 1959 the runoff has consisted of mostly spring events, with no unusual events, and low daily flows. The following trends have been observed: In the last five years the bank slopes have generally decreased by 5 to 10 percent in all reaches. The transition at the upper end of the channel improvement was not initially stabilized and headcutting worked upstream through the transition until it reached a railroad bridge. The channel bed erosion in the transition, supplemented by bank cutting, resulted in raising the bed in the upper test reach about 2 feet in 1959. Heavy riprap dumped just below the bridge has now stabilized the transition, and because of this the channel bed now has degraded almost to its original position. The sediment wave from the upper test reach had moved by 1964 to the middle test reach, causing a slight aggradation of the channel bed there. The lower test reach has been degrading slightly, because of the removal of a low dam and considerable channel clearing of vegetation just below the project. Periodic surveys will be continued so that future trends of channel adjustments can be documented and interpreted. (SWC 1-a1)

Previous model studies at the Sedimentation Laboratory, reported in 1963, showed that the average angle of repose for fine sands (D_{50} = 0.12 mm.) was 29° under water and 9° above water. Field surveys made this year of the Fisheating Creek drainage channel in Florida, which was dug in such sands, confirmed the hypothesis that channels dug to a trapezoidal shape in these soils would evolve into an elliptical shape. It was further determined that most of the banks sloughed off during the first year or two after construction and tended to become stable thereafter. Thus, the design of dug channels in this area may well be modified. (SWC 1-bE4)

The comprehensive study of upland stream channel behavior which was initiated in southeastern Nebraska in 1963 was continued. The study, when completed, will encompass 150 channel reaches with contributing drainage areas ranging from 50 to 1,300 acres. Detailed surveys and assessments of reach geometry, cross sections, bed and bank materials, degree of vegetation protection, hydrologic and hydraulic factors and other environmental influences are being performed. During the past year, 50 reaches were surveyed and hydraulic and hydrologic factors were determined for 44 reaches. The investigations are designed to provide information on stability of small channels as pertinent to the small watershed program in this area. The Soil Conservation Service is cooperating in the field investigative phases of the study. (SWC 1-18 (d3))

The width-depth ratio of the Washita River and tributaries under study at Chickasha, Oklahoma, has been found to increase with increase in average percent sand in the measured sediment load. For ten of the twelve channels studied, the relation was $Y = 0.169 X + 3.552$, where Y is the width-depth ratio and X is the average percent sand in the measured load. In order to predict the amount of downstream channel changes that can be attributed to upstream watershed treatment, it is necessary to have quantitative relationships of the variables that determine a river's character. This finding may have much significance in evaluating the effects of conservation works upon stability of stream channels in the area. (SWC 1-e2)

The ages of two buried soils from lower terrace deposits of the Washita River, in the vicinity of Chickasha, Oklahoma, were established by carbon-14 determinations made by the Sedimentation Laboratory. The oldest soil, 10 feet below the terrace surface was dated as 1,760 $\pm$ 150 years and the younger soil, 8 feet below the terrace surface, was dated as 1,000 $\pm$ 100 years. The successful dating of these buried soils is very encouraging. Plans are now underway to locate other buried soils from greater depths below the terrace surface. If these are found and successfully dated, they will provide a calendar with which the past geomorphic history of the Washita River can be correlated and another insight essential for evaluating any changes in channel regimes associated with conservation works in upstream tributary watersheds. (SWC 1-e1)

Geomorphic reconnaissance of the Walnut Gulch Experimental Watershed, indicates that its channel system was cut down through relatively coarse gravels of the Tombstone terrace, laid down during the Illinoisian glacial period, and into fine-grained Middle Pleistocene sediments. Valleys originally cut into these finer sediments have been refilled with sediments from erosion of the younger deposits, still overlying the upper portions of the watershed. Carbon dating of fossils in these deposits by the Sedimentation Laboratory indicates the degradation-aggradation processes involved in development of the present drainage system have taken place over a period of about 21,000 years. These processes are continuing, probably as modified mainly by climatic changes. (SWC 1-g2)

3. Stability of channels in cohesive materials. Studies at the Sedimentation Laboratory have shown that the cohesive qualities of clay soils that contribute to stability, or lack of it (erodibility), are due to properties that may logically be classed into three groups: (A) the inherent types that include the kind and texture of the clay mineral, the amount of clay mineral, and the texture of the noncohesive portion of the soil; (B) the semipermanent properties that result from influences of recent geologic or man-made environment, such as bulk density, dispersion or aggregation of the finer portions, organic or other chemical contaminants, and the extent of orientation of the particles; and (C) the associate properties that are moisture-time-temperature related, and are basically related to the other properties, but which are subject to variation, such as the moisture content when first subjected to the erosive force, the wetted age prior to erosion, the length of time subject to erosion, and the temperature of the eroding water. (SWC 1-bE4)

The following are some observations at the Sedimentation Laboratory regarding stability of cohesive materials, based upon approximately 2,590 rate-of-erosion values of 45 different cohesive materials:

Plasticity Index. The plasticity index should not be considered as a good index of the stability of a soil against hydraulic erosive forces. Its use for this purpose should be contingent upon proof of good correlation, resulting from intensive, controlled experimentation yet to be done.

Wetted Environment. Laboratory tests on a large number of cohesive soils show that maximum erosion rates for a given hydraulic erosive flow condition increase as the influence of wet aging, which induces stability, decreases.

Antecedent Moisture. Most soils exhibit an increase in erosion rate with increase in water content at the beginning of the erosive event, up to an intermediate water content; and then decrease in erodibility with continued increase in water content to near-saturation.

Water Content of Soils at Their Maximum Erodibility. For those soils investigated in this respect, the water content at greatest erodibility increases from soil to soil as erodibility increases, up to a point of near-saturation. Those soils having peak erosion rates at near-saturation did not gain stability with an increase in wetted age. (SWC 1-bE4)

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

Sediment Sources and Yields from Agricultural Watersheds

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Stream Channel Morphology and Means and Measures for Stabilization

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AREA 2: HYDROLOGY AND WATER RESOURCES RELATED TO AGRICULTURAL WATERSHEDS

Problem. An insight into the operation of the hydrologic cycle in agricultural watersheds is one of the essential segments of knowledge required for successful development, management, and utilization of the Nation's soil and water resources.

There are nearly 12,000 watersheds in the country in the size category commonly encompassed in developments under the Watershed Protection and Flood Prevention Act, the Small Reclamation Projects Act, and similar programs. About 8,300 of these watersheds need project action for development of flood prevention systems, water supply, public recreation areas, and irrigation and drainage enterprises. In addition, it will be necessary to evaluate the hydrologic performance of all these watersheds in connection with programs of comprehensive river basin planning now in progress and projected for the future.

Research-derived procedures for estimating floodflows, water yields, hydrograph shapes, base flow, and ground water accretions in relation to the use and treatment of watershed lands in the various geo-climatic regions of the country are an urgent need. Research on relations between improvement works in upstream tributaries and floodflows and water yields downstream along the principal tributaries and the main stems of major rivers is also a conspicuous need.

This research seeks new knowledge of hydrologic processes in agricultural watersheds. From it are derived prediction equations and criteria for the more efficient design of watershed programs and utilization of water resources.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program involving engineers, geologists, meteorologists, soil scientists, ecologists, and statisticians in both basic and applied research on the hydrology of agricultural watersheds. The primary purpose of this research is to provide hydrologic guidelines for the formulation of an adequate system of interrelated structural developments and associated land treatment measures for the best use or combination of uses of land and water resources within upstream watersheds and the river basins of which they are tributary.

The scientific effort directed to this area of research totals 53.0 professional man-years. Of this number, 7.7 are devoted to studies of precipitation patterns; 10.6 to soil moisture accretion and depletion; 4.4 to ground water accretion, movement and basin recharge; 6.0 to aquifer-streamflow relationships; 12.1 to water yield and water supply and quality; and 12.2 to floodflows and storm runoff.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are currently engaged in research on the varied aspects of the hydrology of agricultural watersheds. Studies are being made on the use of radar to characterize rainfall and the effect of interception of rain and snow on moisture available for plants.

Work is also underway on the effect of watershed cover on the exchange of moisture between the soil and the air. The experiment stations are cooperating closely with the Weather Bureau in analyzing precipitation records for use in predicting precipitation probabilities. Regional projects NC-26, NE-35, and W-48 are concerned with analysis of climatic patterns and their relationship to agriculture.

Research is being conducted on hydrologic characteristics of ground water basins, ground water recharge in rice areas, and on the relationship between surface and subsurface hydrologic phenomena.

Improvement in forecasting both annual and seasonal water supply by more effective snow course measurements and analysis and the relationship of runoff rates and water yield to land use practices are being studied. The Southern regional research project S-53 is concerned with the factors affecting water yields from small watersheds and shallow ground aquifers.

The total research effort in hydrologic problems related to agricultural watersheds at the State experiment stations is 46 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Precipitation Patterns

1. Precipitation amounts. The Hydrograph Laboratory, Beltsville, Maryland, has developed a procedure for estimating probable maximum rainfall amounts for durations of 5 minutes to 24 hours at any location in the conterminous United States. The procedure makes use of available maps giving means and standard deviations of rainfall for selected periods. The number of standard deviations required to be added to the mean to exceed all observed events, designated as probable maximum rainfall, is inversely related to the mean and

directly related to the duration of the intensity to be predicted. This relationship has been presented in graphical form. Probable maximum rainfall is a determining factor in sizing hydraulic structures when the calculated risk must be minimized. (SWC 2-aD1)

Guidelines as a first approximation for spacing raingages in a watershed network were evolved by the Hydrograph Laboratory from analyses of flood producing rainfall data from networks on 30 watersheds in various climatic regions of the country. The coefficients of correlation between storm rainfall at adjacent gages were plotted against distance between gages and showed a well-defined distinction in raingage spacing for a given correlation coefficient in the wettest and driest climates. For a correlation coefficient of approximately 0.9, a raingage spacing of 6 miles was indicated for the humid Pigeon Roost Creek Watershed in Mississippi, but a spacing of less than 1 mile was indicated for the semiarid Walnut Gulch Watershed in Arizona. This finding not only provides a first guide to design of precipitation networks to study upstream hydrology, but is an implicit expression of the great spatial variability of the storms that produce upstream floods. (SWC 2-aD1)

The hydrology data collected on Sleepers River Watershed, near Danville, Vermont, were analyzed to determine effects of precipitation-intensity patterns, storm duration, and areal distribution of precipitation upon hydrograph timing or basin lag. No correlation was found between storm-intensity patterns (advanced, uniform and delayed) and basin lag. It was not determinable whether this result was due to interaction of the storm-intensity with areal coverage and storm duration. Storm duration was a significant factor when the basin lag determination was based on the center of mass of rainfall, but not when based on maximum rainfall intensity. Since the latter was not significant by itself in determining basin lag for this watershed, it would appear that storm duration is a significant factor in relation to basin lag. Areal distribution of precipitation affected the basin lag significantly. A storm concentrated in the upper portion of the watershed produced a basin-lag time of 30 percent greater than the average, and one concentrated in the lower portion of the watershed produced a basin-lag time of 15 percent less than the average. This study emphasizes that misleading answers are obtained when the basin lag is computed from watershed characteristics only, since, in this case, the storm is assumed to be of short duration and uniformly distributed over the watershed. (SWC 2-a1)

Rainfall records for the Upper Taylor Creek, Indian River Farms and Monrieve Ranch experimental watersheds were processed and analyzed at Fort Lauderdale, Florida, because the seasonal pattern of rainfall has a significant bearing on the design of all agricultural water use and control structures. These data show that the heaviest rainfalls normally occur from June through September, with near-drought conditions in November, December, January, and February. Most summer rains fall as short-duration, local, afternoon thundershowers. Such showers, exceeding 2 inches in 2 hours, are not uncommon. Summertime day-long storms are usually associated with

tropical storms. These tropical storms, which occur mostly from July to mid-October and average only one or two per year, on occasions have released a storm total in excess of 10 inches in 24 hours. Heavy rainfalls, however, have occurred every month in the year. (SWC 2-b2)

A frequency analysis of drouth duration for the 27-year (1938-64) period of record on the Blacklands Experimental Watershed, Riesel, Texas, indicated that a 3-month drouth will occur on the average of once in 50 years, and a 1-month drouth will occur about every year. In this study a drouth is defined as a period of 14 days or more with not more than 0.25 inch of rainfall in any one 24-hour period. The duration and frequency of drouth conditions must be taken into account in the design of dependable surface water supplies from upstream watersheds. (SWC 2-e1)

Three extreme rainfall events have been recorded in 4 years of data collection on the Lowrey Draw Experimental Watershed at Sonora, Texas. Observed point rainfall for a 1-hour period equalled or slightly exceeded U. S. Weather Bureau 100-year amounts of about 4.5 inches on June 15, 1961, and July 29, 1964. Maximum point rainfall for a 7-day storm period, September 19-25, 1964, was 12.12 inches. This approximated a 100-year event in accordance with U. S. Weather Bureau publications. (SWC 2-e1)

At Chickasha, Oklahoma, determination of average daily rainfall on 12 tributary watersheds and 6 main stem reaches of a 1,130-square-mile study reach of the Washita River showed no significant differences between the Thiessen and arithmetic methods of averaging. Watershed or reach size in this study ranged from 0.88 to 426 square miles. The number of rain gages used in the averaging ranged from 3 for the smallest to 66 for the largest watershed or reach, with a total of 184 recording rain gages in the 1,130-square-mile area. Differences in annual rainfall over the 1,130-square-mile area ranged from 13.22 to 15.22 inches for the 3-year period 1962-64. These great differences in precipitation are directly reflected in the water supplies of the local areas. (SWC 2-e1)

Work at Moscow, Idaho, with an analog field plotter has established its utility in determining streamlines of air currents over the mountains. Typical profiles of annual precipitation appear to correspond with the wind streamlines. Therefore, the analog field plotter is a convenient device for estimating the precipitation between wide-spaced rain gages in mountainous topography. (SWC 2-f4)

For the period of record (1954-1964) rainfall on the Walnut Gulch Watershed has averaged about the same for the months of July and August. However, practically all the runoff-producing rainfall fell in July and September in 1964, and, as in two of the past four years, none occurred in August. Monthly and seasonal totals of rainfall also varied widely within a small area. The 1964 maximum summer point-rainfall on the Walnut Gulch Watershed (58 square miles) was almost 3 times the minimum. This indicates

very limited relationship in the Southwest between monthly and seasonal average rainfall, and especially their point-values, to either the available moisture for forage production on a watershed or yields of water for off-watershed use. (SWC 2-g1)

Significant information on orographic influences upon winter frontal-type storms has been documented by the small network of recording rain gages in the vicinity of Tehachapi, California. The September to June precipitation for the two years of record has averaged about 8 inches at 4,000 feet elevation, compared with over 18 inches at 6,000 feet. The average precipitation at all stations in the network for 8 storms of over an inch of rainfall, 1963-64, exceeded the catch of the nearest U. S. Weather Bureau station at Tehachapi by more than 100 percent, and some gages at higher elevations recorded a catch greater than 400 percent that of the U. S. Weather Bureau gage. In only one case was the catch, even at the lowest elevation gage in the net, less than at the U. S. Weather Bureau gage, and in that storm the higher elevation gages exceeded the catch at Tehachapi by as much as 100 percent. This indicates a general inadequacy and serious bias in most previous precipitation records for intermountain areas of the West, where practically all gages have been located in the valleys. (SWC 2-g1)

2. Rainfall intensity-duration. In Pigeon Roost Creek Watershed near Holly Springs, Mississippi, high-intensity rainfalls that exceeded normal rainfall expectancy were recorded for the second successive year by the dense rain gage network. The storm of July 11, 1964, was significant in that 5 gages recorded maximum 20-minute rainfall amounts that exceeded the probable maximum in 100 years; and 3 gages had maximum 40-minute amounts that exceeded the probable maximum values for a 50-year period. Following similar occurrences in 1963, these events again illustrate the need of a closely spaced network of gages, rather than longer records, to correctly define storm frequency at point locations within agricultural watersheds. (SWC 2-b2)

At Chickasha, Oklahoma, a study of the characteristics of extreme rainfalls showed the thunderstorm of May 9, 1964, to be unusually severe. The heavy rain was accompanied by hailstones as large as 3 inches in diameter. Maximum point rainfall at the storm center was 6.14 inches. Maximum 15-, 30-, and 60-minute intensities were 9.56, 6.08, and 3.73 inches per hour, respectively. The 15-minute intensity exceeded that expected once in 100 years and the 30- and 60-minute intensities exceeded the expected 50-year value. Storm totals of 5 inches in 3 hours are common in the area. (SWC 2-e1)

An analysis of rainfall intensities in the mountainous Reynolds Creek Experimental Watershed in southwestern Idaho revealed that essentially the same proportion of the total annual precipitation falls at high intensity regardless of elevation. Since in Reynolds Creek there is, in general, an increase of 5 inches of precipitation per 1,000 feet increase in elevation, there is likewise more high intensity rain at the higher elevations.

Rainfall intensity plots as a straight line against the logarithm of the amount falling at that intensity, giving a set of parallel lines positioned in relation to the total precipitation. (SWC 2-f2)

3. Rainfall depth-area relations. The mean depth-area relation for 15 high-intensity, 24-hour storms on Upper Taylor Creek Watershed, near Vero Beach, Florida, indicates that for such storms the average rainfall over a 100-mile square area is 66 percent of maximum point rainfall; average rainfall over a 50-mile square area is 82 percent of maximum point rainfall; and average rainfall over a 20-mile square watershed area is 92 percent of maximum point rainfall. The results of this analysis can be incorporated into existing rainfall-runoff procedures used for estimating the hydrologic design of channels and structures for water control. (SWC 2-b2)

At Tucson, Arizona, analyses of the data collected over the past 10 years by the dense networks of recording rain gages on the Walnut Gulch and Alamogordo Creek Experimental Watersheds show that rainfall depth-duration does not follow the straight-line relationship suggested by U. S. Weather Bureau Papers 28 and 40, and that for short durations the rainfall intensities are probably much higher than those curves indicate. Apparently, the existing data from the widely spaced rain gages in the national network are very inadequate for rainfall depth-duration estimates where design floods result from summer thunderstorms, as is the case for small watersheds in the Southwest. (SWC 2-g1)

4. Rainfall directions. Continued vectopluviometer reconnaissance studies at Lompoc, California, have further confirmed the indication that rainfall is typically angled to the horizontal in its fall, both at valley and hillside sites; that both the horizontal and vertical directions of rainfall are restricted to substantially narrower angular ranges on hillsides than at level (valley) sites; and that the heavy rains (storms exceeding 1 inch) are much more restricted in their direction of fall than are lighter storms. The horizontal directions of fall of five storms, exceeding 1 inch, at a sample hillside site, were confined to a horizontal sector of less than 45°, and within a vertical sector 35° to 59° from the horizontal. This reconnaissance study indicates the need and possibility for substantial improvement in estimating the areal distribution of inputs of rainfall and rainfall erosive energy on watersheds, with respect to varying aspect and steepness of slopes. (SWC 2-g1)

5. Snow depths. Photogrammetric techniques were used to determine snow depths on a small study area in the Reynolds Creek Experimental Watershed in southwestern Idaho. These depths, determined by subtracting ground elevations from snow elevations at grid points, consistently exceeded measured depths by 0.5 to 1.0 foot. This bias was largely due to sinking of black paper control markers, caused by radiation, and to the recognized tendency of stereoplotters to read elevations low on dark surfaces and high on light.

The calculated standard deviation of snow depth measures photogrammetrically was 0.8 foot at a photo scale of 1:6000, compared with a standard deviation of about 0.15 foot for direct measurement in the field. (SWC 2-f2)

The pressure pillow method for measuring snow water equivalent, first investigated as to practicability by the University of Idaho under an ARS research contract, is undergoing further testing and evaluation on the Reynolds Creek and Sleepers River Experimental Watersheds in Idaho and Vermont, and also by various other Federal and State agencies, universities, and private institutions. The pillow is made of synthetic rubber, 12 feet in diameter, and filled with a mixture of methanol and water. It operates on the principle that pressure exerted by a given amount of snow on the pillow is directly related to the water content of the snow. Various possibilities exist for converting these pressure changes to water equivalents, and telemetering of results from remote inaccessible locations. Approximately 100 such pillows were in operation on a trial basis in the winter of 1964-65. Experiences to date are promising, and while it is not yet known that the pillows will operate successfully in all environments, it does appear that the pressure-pillow system has the potential of reducing time-consuming manual measurements of snow depths and, at the same time, providing information from remote areas which otherwise could not be sampled. (SWC 2)

At Moscow, Idaho, snow measurements were made at low elevations and correlated with measurements made at high elevations, by the Soil Conservation Service. A linear relation was established for snow-moisture content versus elevation for several watersheds. Moisture content increase versus elevation increase was greatest on west-facing slopes of mountain ranges. The increase in moisture versus elevation ranged from 7.1 inches per 1,000 feet at Lolo Pass to 21.8 inches per 1,000 feet at Wallace. Such correlations should provide a means of more accurately assessing the snow melt water from high elevation areas where physical measurement is not possible. (SWC 2-f1)

B. Soil Moisture Accretion and Depletion

1. Infiltration. A program was initiated during the year, under leadership of the Hydrograph Laboratory, Beltsville, Maryland, to define and characterize the infiltration and storage capacities of 200 soils (300 soil-vegetation complexes) occurring on selected ARS research plots and experimental watersheds. This characterization of soils, based upon total porosity, moisture-tension relations and the hydraulic conductivity of each horizon, identifies the least permeable horizon in the soil profile and provides a basis for computing infiltration capacity (volume of water storage) in the soil profile before the infiltration rate becomes constant. Thus a new rationale is being evolved for calculating precipitation excess on a watershed basis wherein infiltration is expressed both in terms of volumes and rates, with appropriate consideration of evapotranspiration to account for antecedent conditions.

This concept for deriving precipitation excess is a primary component in the rational mathematical model being derived by the Hydrograph Laboratory for the prediction of streamflow hydrographs resulting from rainfall events of various intensities and probabilities. (SWC 2-aD1)

The potential effect of infiltration and soil moisture storage upon floodflows in upstream tributaries is indicated by the following observations on the North Appalachian Experimental Watershed at Coshocton, Ohio. Soil moisture observations before one of the major storms of the 28-year record showed that 1.85 inches of water could be absorbed in the top 7 inches of soil (saturation deficit) and 2.36 inches of water could be absorbed in the top 14 inches of soil. Of the 2.50 inches of storm rainfall there was 0.69 inch of runoff and soil moisture storage increased 1.81 inches--practically the same as the amount of saturation deficit in the top 7 inches of soil. Very little of the available soil storage space below 7 inches was used during this severe storm period. The study points out the need for developing soil management practices to permit the absorption of storm rainfall to greater soil depths. In this example, had storm water been able to penetrate quickly into the pore space in the top 14 inches of soil, there would have been only 0.14 inch of runoff, and no flood. (SWC 2-c3)

2. Soil moisture balance. At Oxford, Mississippi, soil moisture depletion from the upper 2 feet of a Memphis soil profile where moisture accretion from rainfall was prevented was measured with the nuclear probe. Three soil-cover conditions allowed measurement of losses due to: (a) percolation alone from plastic-covered soil; (b) percolation plus evaporation from bare soil; and (c) percolation plus evapotranspiration from sod. Moisture depletion was very rapid during the first 20 days of the experiment for all conditions. Evapotranspiration by grass exceeded the combined losses due to evaporation from bare soil and percolation from plastic-covered soil during the first 40 days of the experiment. Soil moisture depletions due to evapotranspiration from the sod cover were almost the same from the 1- and 2-foot depth profiles. Percolation losses under plastic were greater than evaporation losses from bare soil for the 2-foot soil profile; however, the reverse was true for losses to a 1-foot depth. This technique is one that shows promise for economically investigating the percolation of water with the nuclear probe. (SWC 2-b4)

Detailed work with the Troxler 102 and 104, and Nuclear-Chicago P-19 probes at the Sedimentation Laboratory, Oxford, Mississippi, verified that their spheres of influence extended some 10 or 12 inches upwards from the bottom of the probe and at least 4 inches below for a maximum vertical sensitivity of 14 to 16 inches. Thus, the probes are of limited usefulness in assessing moisture conditions in the uppermost part of the profile--the part that strongly influences the hydrologic performance of watersheds. (SWC 2-b4)

At Madison, Wisconsin, the amount of soil moisture on the research watershed near Colby was predicted, to a practical degree, by using antecedent precipitation values for the 2-month prior period along with seasonal adjustments for climate and crop stage. As soil moisture is a key factor in rainfall-runoff relations, its evaluation will aid in predicting floodflow volumes in this region where water power and flood control programs are important economic factors. (SWC 2-c3)

Work was continued at Riesel, Texas, during the year for defining the role of soil moisture in rainfall-runoff relations in the Texas Blackland Prairie Land Resource Area. A comparative plotting of soil moisture in the 3-foot profile, SM_{0-3}, and soil moisture in the 3- to 5-foot profile, SM_{3-5}, was made to determine the relative accretion and depletion characteristics. Trends were examined for durations of several months by "wet" and "dry" periods. When SM_{0-3} was near field capacity, the SM_{3-5} increased even though little rainfall occurred during the period. When the SM_{0-3} was less than approximately one-half of total water-holding capacity, SM_{3-5} decreased with or without rainfall. The maximum available SM_{3-5} was found to be approximately 5.0 inches. Based on the comparisons made, it was determined that when SM_{0-3} was greater than 5 inches and SM_{3-5} was less than 5 inches, then SM_{3-5} increased at a rate of approximately 56 percent of the moisture dissipated from the SM_{0-3}. When SM_{3-5} approached 5 inches, some percolation to greater depths probably occurred. These observations form a key part of the procedure for predicting floodflows and water yields being developed at this location. (SWC 2-e2)

Data for a native grass meadow watershed, for the period 1956-63, were analyzed at Riesel, Texas, toward further development of the runoff prediction equation mentioned above. Moisture dissipation constants were developed by season, using soil moisture, mean daily pan evaporation, and mean daily temperature as indicators. Available soil moisture in the 3- to 5-foot profile was included in the procedure. Restricting limits were placed on dissipation constants, including a fixed rate for low moisture conditions. Percolation below the 3-foot profile was used during periods of high soil moisture. The procedure was tested on the watershed using a very dry 10-year period of record in which rainfall and runoff, but not soil moisture data was available; the total predicted runoff was +11 percent in error. For 1957, a high rainfall year, the predicted runoff was in error by +11 percent. (SWC 2-e2)

A study of the effect of antecedent moisture level (varied by sprinkling) on runoff from grass sites on the Walnut Gulch Experimental Watershed indicated that for a 0.90-inch storm having a maximum 5-minute intensity of 1 inch per hour, there would be twice as much runoff when the surface soil was at field capacity as when dry. However, with a 2.0-inch storm with maximum intensity of 6 inches per hour, runoff from a wet soil would be only 8 percent more than from a dry soil. A set of regression lines was developed from results of this experiment, relating the depth of on-site runoff and

rainfall, for maximum 5-minute rainfall intensities varying from 0.5 to 6.0 inches per hour, on wet and dry soils. (SWC 2-g2)

Comparison of the seasonal runoff from small unit-source watersheds within the Walnut Gulch Experimental Watershed with that from associated 6- by 12-foot plots showed much less net runoff from the watersheds in both 1963 and 1964, indicating substantial abstraction from the runoff in the headwaters areas as well as downstream in the major channels. That much of this abstraction from the on-site runoff occurs even in the overland flow stage, was indicated by soil moisture penetration at one moisture measurement station compared with another about 125 feet downslope. Whereas available moisture existed at the 18-inch depth for only 17 days at the upper site, moisture remained above the wilting range for 95 days at the lower site. That infiltration at downslope sites is partially supplied by the runoff from upper sites has been generally indicated by numerous soil moisture measurements over the past two years, on both brush and grass-covered unit-source watersheds. (SWC 2-g2)

3. Vegetative cover. Experience to date with color aerial photography for resource inventory on the Reynolds Creek Experimental Watershed has indicated that: Interpretation and mapping of vegetation is enhanced significantly, particularly in areas of complex relief and topography; geologic mapping is improved where different geologic units occur in contrasting colors; and color aerial photos are of great value for the interpretation and mapping of soils in this semiarid rangeland area. (SWC 2-f3)

4. Watershed evapotranspiration. Three years of data from three research watersheds, about 17 to 43 square miles in size, at Danville, Vermont, indicate that actual evapotranspiration is essentially equal to the potential as computed by the method of Thornthwaite and Mather. Actual ET in this case was derived as the difference between measured precipitation (P) and streamflow (Q) for a water year from May 1 to April 30--beginning and ending when soil moisture is approaching saturation conditions and there is no residual effect of snow to be carried over to the next year. The annual P-Q residual does not exhibit large variations and the geology of the watersheds indicates no likely losses to deep seepage or to underground aquifers. The same general agreement between actual and potential ET was also noted for several 3-month periods but no close agreement for shorter time periods was found. Data interpretations along these lines will be continued as additional information becomes available. (SWC 2-a2)

The ratio of U. S. Weather Bureau pan evaporation to evaporation from lakes and ponds continued to hold at about 0.81 for southern Florida on the basis of studies at Fort Lauderdale. Data from evapotranspirometers, land tanks, evaporation pans, and related meteorological information have been collected and used to evaluate procedures for computing evaporation. It was concluded that the Fractional-Evaporation Equivalent Method, using measured insolation rated highest and seemed best suited where records are available

and can be correlated with temperature. A study this past year expanded the use of this method to other climatic regions where daytime humidity is known. A simplified theoretical model, using the kinetic theory of matter, was utilized to explain the relationship observed between the percent of insolation used to evaporate water and the mean monthly temperature. (SWC 2-b1)

Instrumentation of a hydroclimate station at Lompoc, California, progressed to an estimated 50 percent of its envisioned level, and was put into operation "with a minimum of instrumentation" in the fall of 1964. Following 1.18 inches of rain over a 27-hour period ending November 12, evapotranspiration from a ryegrass site (measured by an electronic weighing lysimeter) was greatest during the first rain-free day, amounting to 0.10 inch during the 10 daylight hours. The ratio of evapotranspiration to net radiation was also maximum on November 13 at 0.77 as compared to 0.37 and 0.67 on the preceding and following days, respectively. During the same period the ratio of ET to pan evaporation averaged 0.86. This ratio was highest at 1.75 for 5 midday hours 1000 to 1500 hours on November 13; and lowest at 0.53 for the ensuing period, 1500 hours on the 13th to 1200 hours on the 14th. It is planned to make similar periodic energy balance studies at this station from time to time, to obtain basic information for representative climatic conditions over the year so that rational prediction schemes for estimating consumptive use and streamflow may be developed. (SWC 2-g3)

Instrumentation and precise geologic surveys were completed to enable development of complete seasonal water budgets of a study reach on the main channel of the Walnut Gulch Watershed (above runoff station 2) at Tombstone, Arizona. Intensive exploration drilling and seismic tests were made to precisely establish aquifer boundaries, and laboratory and field tests were made to determine their hydraulic properties. Soil moisture inventory and ground water levels measurements were maintained to evaluate inflow-outflow and storage changes in the valley alluvial materials through the 1964 runoff season. The data are currently being prepared for computer analyses. Instrumentation was started also, and is being carried forward, to develop seasonal energy budgets so as to determine both the transpiration of riparian vegetation and direct evaporation from the barren streambed surface. Comparisons of the water and energy budgets of this study reach of channel may permit evaluation of influencing factors for prediction of water budgets of other ephemeral stream channels in the Southwest. (SWC 2-g3)

C. Ground Water Accretion, Movement and Basin Recharge

1. Ground water movement. Monthly measurements in selected observation wells continued to show only relatively minor fluctuations in ground water levels in the Meridian Formation, which is the principal aquifer beneath the Pigeon Roost Creek Watershed near Holly Springs, Mississippi. Annual water loss from the basin due to deep percolation and subsequent lateral seepage outflow via the Meridian was computed to be about 3 surface inches, and stable piezometric gradients for the past several years had led to the conclusion that such losses were steady. The relatively constant ground

water levels during the past three years when rainfall was 20 percent below normal tend to reconfirm previous evidence that the vast quantity and movement of ground water underlying the study area is not readily affected by short-term variations in rainfall on the watershed. (SWC 2-b4)

The heavier than average rains in August, September, and November, and the annual fall-winter reduction in evapotranspiration caused a rise of water levels in most observation wells in the Washita River study reach at Chickasha, Oklahoma. By the end of 1964, however, levels in many wells had started to decline again and in most wells there was a net decrease in the water table elevation during the year. Thus, the general decline of ground water levels that began in late 1959 and early 1960 appears to be continuing. These declines probably indicate a decrease in ground water throughout the watershed, which portends another year in which the tributary streams will become dry--unless countered by above-average rainfall. (SWC 2-e4)

Rainfall was less in 1963-64 than any of the previous seven years of study in the Lompoc sub-area of the Santa Ynez Basin in California, and rainwater penetration was less than any previous year at 7 of the 10 measurement sites. Only at a site of bare Marina sand was there a deep translocation of moisture. Here an estimated 3.85 inches passed through the 20-foot measured depth. Though 1963-64 rainwater penetrated only to 3.5 feet on a weed-grass site, it is significant that an estimated 0.9 inch of water from 1962 rainfall stored deep in the profile moved beyond the depth of measurement. This confirmed previously observed trends for continued downward unsaturated flow of moisture, once below the depth of the apparent root zone, and points up possibilities for increasing recharge even in this low rainfall area. (SWC 2-g3)

2. Basin recharge. Studies on the Lowrey Draw Watershed at Sonoro, Texas, continued to show the potential for ground water recharge in the Edwards Plateau that may result from floodwater-retarding structures actually constructed for another purpose. One reservoir with a 5,392-acre watershed received an inflow of 957 acre-feet in the 6-day storm period of September 19-24, 1964. Of this amount, 668 acre-feet were detained by the reservoir, yet by the fourth day following the end of rainfall the reservoir was dry. Wells near the reservoir showed rises up to 86 feet, indicating a large dome of water beneath the reservoir well above the general ground water level. Cavern openings in the reservoir bottom were responsible for the rapid entry of water into the ground. Though the specific disposition of this recharged water is unknown, it is a reasonable assumption that it is stored and recoverable. (SWC 2-e4)

Continuation and expansion of the seismic refraction studies for delineation of aquifers in the Reynolds Creek Experimental Watershed were carried out during the 1964 field season. Investigations were made of the deeper portions of the stratigraphy to locate the depth of the Hoot Nanny basalt. Lake sediments were found to overlie the valley floor to depths in excess of 600 feet. Data from the seismic refraction studies and from geologic mapping

were used to construct a pre-Hoot Nanny basalt erosion surface for the Reynolds Creek Watershed. Ground water levels in the low rainfall area (yearly average of about 9 inches) rose an average of 2 feet following the heavy December rains with a maximum rise of 22 feet in one well. The greatest recharge occurred in the regions of basalt outcrops. These investigations constitute a key element in the comprehensive investigations for developing rational procedures for predicting the water yields of ungaged streams. (SWC 2-f1)

Intensive geologic exploration and ground water level measurements are underway on the Walnut Gulch Watershed to determine the ultimate disposition of the channel "losses", the extent to which they contribute to the regional ground water available for downstream use, and the recovery potential for that portion not reaching a regional water table. Studies have been intensified also to evaluate evaporation losses from channel beds, and the nonproductive consumption by riparian vegetation. These represent true losses and their reduction offers a potential for increasing the net water yields of semiarid watersheds. (SWC 2-g3)

Two years' water table level records have been collected for four observation wells in the deep valley fill, in the vicinity of the main outlet (runoff station 1) of the Walnut Gulch Experimental Watershed. These wells are instrumented with Keck battery-powered water-surface sensing devices, attached to Friez Model FW-1 recorders. Records to date indicate: (1) development of a substantial ground water mound in the regional water table following major surface flows; (2) large amounts of water moving underground, down channel; and (3) little lateral flow in or out of the valley alluvium. Based on observations at these wells and on further exploration drilling, it is planned to install several additional ground water observation wells in the vicinity and to make pumping tests of the aquifers involved, to evaluate ground water storage changes and ground water outflows from the watershed. A similar program of ground water accounting is planned also for the Alamogordo Creek Experimental Watershed near Santa Rosa, New Mexico. (SWC 2-g3)

D. Aquifer Streamflow Relations

1. Subsurface contributions to streamflow. Work was continued at Danville, Vermont, to establish values for the recession constant K in the equation $Q_t = Q_o K^t$; where Q_t is discharge at time t, Q_o is initial discharge, t is time, and K is a recession constant. Data from three watersheds in tandem on the Sleepers River Experimental Watershed indicated that a K determined from individual recession periods on a watershed was about the same as a K derived using all of the recessions for a watershed. The data used in the analysis also indicated that K gradually increased from summer through the late fall and generally increased with size of watershed. The constant K is a parameter that may be used as an indicator of the subsurface storage in a watershed. (SWC 2-a2)

Pressure levels in two key artesian wells on the research watershed near Vero Beach, Florida, have declined approximately 5 feet in the 5-year period 1959-64. At the same time, the ratio of runoff to rainfall for the watershed increased from a former normal of 43 percent prior to 1959 to a new normal of 55 percent since 1959. This increase is apparently due to new artesian supplies that have been developed for agricultural and urban use since 1958. The base flow contribution from artesian wells was computed to be about 7 inches annually; most of which was supplied during the dry season period from November through May. An undetermined number of artesian wells are allowed to flow continuously for decorative waterfalls, artificial lakes, and ponds. If areawide piezometric levels continue to decline it may be desirable for authorities to impose restrictions that limit well discharges to proven beneficial uses, consistent with long-time aquifer recharge rates. (SWC 2-b4)

An analysis of 8 years of storm runoff data on claypan soils near McCredie, Missouri, has definitely established that interflow takes place when the rainstorm occurs on wet claypan soils. However, when the rainstorm falls on dry soil, surface runoff from long slopes may be absorbed before it reaches the stream system. Measurements of runoff after prolonged sprinkler irrigation on Mexico silt loam with meadow cover in 1964 showed that yield of water per unit area increased at a rate of 0.06 inch per 100 feet of slope length up to 320 feet, the maximum length studied. This increase represents the contribution of interflow for the wet soil condition. (SWC 2-c5)

Geologic exploration of the rock aquifers at the North Appalachian Experimental Watershed, Coshocton, Ohio, indicates that the major part of groundwater storage important to streamflow occurs at depths less than 30 feet below the land surface. Springflow and the dry weather yield of surface streams were related directly to water level fluctuation in selected shallow wells (20 to 30 feet deep) in fractured rock. Sources of subsurface water, important to the evaluation and prediction of dependable water supplies and the influence of land management can thus be studied from systems of shallow wells. It appears, also, that this aquifer storage fluctuates widely and is affected largely by year-to-year percolation. Water levels at greater depths beneath the broad ridges, where rock strata have few and isolated fractures, show only small changes in aquifer storage and have little effect upon aquifer contributions to streamflow. (SWC 2-c5)

Subsurface watershed divides seldom coincide with surface drainage basins at the North Appalachian Experimental Watershed. However, studies of well and springflow relationships have shown that this variation in catchment area is not important in water yield studies. This finding reduces the need for expensive and difficult drilling and recording of water levels into the deeper, less fractured rock strata. (SWC 2-c5)

A study was initiated in 3 counties in southwestern Wisconsin to determine dependable base flow on 33 watersheds ranging from 0.52 to 141 square miles in size. Streamflow was measured at each of these sites on the average of once each month during the ice-free period, with no measurements being made within a few days after precipitation that might have resulted in surface runoff. Base flow on the streams south of the main divide (U. S. Highway 18) showed a fairly good relationship to drainage area size, and flow per unit area increased with an increase in size of drainage area. The relationship was not so well defined for those streams flowing north from the divide and the flow per unit of area appeared to decrease with an increase in size of drainage area. The underlying rock of this area has a slight slope to the south and the stream gradients appear to be flatter in this direction. A thorough investigation of topography and geology of these areas may account for the apparent reversal in drainage area-base flow relations on opposite sides of the divide, thus permitting more accurate estimation of water yields from upstream watersheds. (SWC 2-c5)

2. Channel transmission losses. Measurements with the nuclear moisture probe in a typical sandbed channel in Pigeon Roost Creek near Holly Springs, Mississippi, suggest that this tool may be suitable and readily adaptable to measurement of channel transmission losses. Although considered tentative and subject to confirmation, one set of measurements before and after a storm event showed an increase in moisture of about 19 inches in the first 10 feet of the soil profile beneath the channel bottom. If one assumes this to be representative of the channel reach, it is equivalent to about 6 acre-feet per mile for the 30-foot-wide channel. (SWC 2-b4)

At Chickasha, Oklahoma, the release of 1,500 acre-feet of water from a large reservoir into the relatively dry Washita River provided the opportunity to obtain measurements of conveyance losses under controlled conditions. Initial conveyance losses were as high as 1.5 acre-feet per day per mile of channel. Final loss rates were about 0.13 acre-foot per day per mile. (SWC 2-e4)

Data from additional runoff measuring stations recently constructed on the main channel system of the Walnut Gulch Experimental Watershed have revealed that runoff transmission losses are occuring in upper channel reaches as well as those previously reported for lower reaches, and that these upper reach losses may, in fact, be relatively high. Transmission losses measured in the past runoff season in an intermediate reach on two occasions exceeded any previously measured, in one runoff event in early summer exceeding 50 acre-feet per mile per hour and in another event approaching 40 acre-feet per mile. This was in a channel reach draining only between 37 and 44 square miles of watershed. (SWC 2-g2)

E. Water Yield and Water Supply

Low flow frequency curves, developed at Fort Lauderdale, Florida, for the Southern Florida Flatwoods Land Resources Area show the minimum flows to be lower than those for most other major land resources areas in Southeastern United States. For example, the minimum 7-day average flow for the 2-year return period is approximately 25,300 gals. per day per square mile for the flat sandy soils of the Coastal Plains as compared with 389,900 gals. per day per square mile for the Southern Piedmont and 1,171,700 gals. per day per square mile for the Blue Ridge Mountains. (SWC 2-b1)

Flow duration characteristics for several Florida experimental watersheds were determined by preparing curves showing the percent of time that flows equalled or exceeded measured rates. The shapes of these curves will be studied to find relations that may exist between the amount and distribution of water yields and watershed characteristics. To supplement these curves, annual rainfall and runoff distribution graphs were plotted, using the pentad (5-day) time system, to indicate time of occurrence of flows shown by the duration curves. Use of the pentad plotting system indicates there may be a correlation between the solar solstitial and equinoctial periods and the annual rainfall pattern and streamflow regime. (SWC 2-b1)

Preliminary analysis of two complete crop rotation cycles, each of three years' duration, have been completed for six 4-acre single-crop watersheds at Hastings, Nebraska. The data show that high runoff from fallowed ground occurs during the last 3 months of the growing season, indicating that more runoff occurs as more of the surface incorporated residues decay. (SWC 2-d1)

The long-term study comparing runoff from a conservation-treated watershed of 481 acres with that from an untreated watershed of 411 acres was terminated at the Central Great Plains Experimental Watershed, near Hastings, Nebraska, on December 31, 1964. Runoff from the treated watershed in 1964 was 1.7 inches, or only half of that from the untreated watershed. The conservation treatments consisted of terracing, grass waterways, and increased amounts of grass in the crop rotations. (SWC 2-d1)

Reseeding of cropland with a mixture of adapted perennial native grasses, two years after seeding, reduced annual runoff on 4-acre watersheds by 94 percent at the Central Great Plains Experimental Watershed. This is indicative of the hydrologic performance of areas that may be placed in various "retirement" programs. (SWC 2-d1)

Studies to isolate and evaluate runoff-producing potentials of range sites were continued at Newell, South Dakota. Information obtained from these studies is useful in determining strategic location for storage and use of water necessary for efficient livestock and range management. On one watershed of 43 acres it was found that 94.7 percent of the 1964 runoff came from a panspot range site which comprised only 18 percent of the surface

area of the watershed. Runoff by range sites over 18 months prior to 1964 showed a panspot range site to yield 36.4 times more water than a sandy range site only 800 feet away. Much of this difference was due to the high intensity of the storms. In fact, differences of as much as 89 times more runoff from a panspot range site than from sandy range sites were noted within the same storm. In 1964, when there were no high-intensity events, runoff was 4.6 times greater at the panspot than at the sandy range site. (SWC 2-d1)

The record period of 671 days without runoff from a 132-acre conservation treated watershed at the Blacklands Experimental Watershed, Riesel, Texas, ended April 25, 1964. Analysis of related data indicate there would have been no runoff from this watershed even had it been without conservation practices. The fact that many areas will have little or no runoff for periods of almost two years regardless of land use treatments emphasizes the need for careful planning of small ponds or reservoirs. This problem is particularly important in an area such as the Blacklands of Texas where little or no ground water is available and most water supplies are stored storm runoff. (SWC 2-e3)

A study at Stillwater, Oklahoma, showed that runoff retained by farm ponds in an agricultural watershed remained about the same from year to year. A 206-acre watershed with 20 percent of its area above three farm ponds experienced a 10-percent reduction in runoff due to ponds when the total runoff was slightly less than 2 inches and 2 percent when the total runoff was nearly 9 inches. Thus, the percentage effect of farm ponds in reducing runoff at some downstream point is less than percent of total watershed drainage area above the ponds and the year to year reduction appears to be about the same absolute amount rather than a percentage. (SWC 2-e4)

At Moscow, Idaho, water yield maps were prepared for northern Idaho and eastern Washington during the year. In the absence of an adequate network of gages on small watersheds along the Canadian border, an estimate of the average annual runoff was based on the trend with elevation. This relationship was checked in the field by observing the type of vegetation in each elevation zone. Water yield was observed to increase on windward slopes until the crest of the Selkirk Mountains was reached. Farther east, leeward of prevailing westerly winds, the water yield decreased rapidly along the Continental Divide. (SWC 2-f4)

At Tombstone, Arizona, studies were initiated in 1964, on dominantly brush-covered sites, of effects on runoff of brush clearing, soil surface pitting, and seeding of native grasses, separately and in combination. Almost 2 inches of runoff resulted from about 6 inches of rain, occurring in 7 storms on the untreated 6- by 12-foot plots. Brush clearing increased the total runoff about 0.5 inch in this first season. Effects of pitting diminished as the season progressed, apparently actually increasing the runoff from the last 3 storms, after about mid-August. Seeding (by spreading a light mulch of native hay) reduced the season's runoff by almost an inch.

Effects of all of the treatments are expected to be considerably modified with time. These studies are being continued on the Walnut Gulch Watershed, and installations were started in the past year for similar studies on the Alamogordo Creek Experimental Watershed in New Mexico, beginning in the summer of 1965. (SWC 2-g2)

F. Floodflows and Storm Runoff

1. Rates of discharge. At Fort Lauderdale, Florida, a graphical analysis of the equation $Q_{24} = K A^x$, where Q_{24} is the maximum 24-hour average runoff rate in c.f.s., K is a coefficient, A is the area in square miles, and x the power-function, was made by plotting maximum runoff rates on log-log graph paper against watershed area for three research watersheds in the Southern Florida Flatwoods. The best fitting equations were: $Q_{24} = A^{.83}$ for the 50-year frequency flood; $Q_{24} = A^{.79}$ for the 10-year frequency flood; and $Q_{24} = A^{.63}$ for the 2-year frequency flood. The amount by which the instantaneous peak-flow rate, Q_p, exceeded the maximum 24-hour average flow rate depended on watershed size and storm intensity. For large watersheds and high-volume storms the two rates differed little, but the spread became greater as watershed size and 24-hour storm intensities decreased. The average Q_p/Q_{24} ratios for these watersheds were: 1.54 for 10 square miles; 1.38 for 25 square miles; 1.24 for 50 square miles; 1.16 for 75 square miles; and 1.14 for 100 square miles. (SWC 2-b1)

Studies of floodflows from watersheds in the 70- to 100-acre size category, in deep loess soil near Council Bluffs, Iowa, showed that, in the first full year of record, the maximum floodflow from grassland was about one-twentieth that from contour cornland--0.10 inch compared with 2.6 to 2.9 inches per hour. Total storm runoff for this maximum event was 0.09 inch from grassland and 0.59 from cornland. The larger volume and higher peak flow for cornland may be major factors in the high rate of gully advance in this area. (SWC 2-c3)

There were a total of 9 storm events on the 2-acre watersheds being used to study the effects of differential grazing upon runoff at the Cottonwood Field Station, near Cottonwood, South Dakota. The heavily grazed pasture had 8 runoff events, the moderately grazed pasture had 7 runoff events, and the lightly grazed pasture had 5 runoff events. The total average runoff was 0.87, 0.32, and 0.05 inch, respectively. In general, total precipitation and rainfall intensities were about the same for the three pastures for all storms. There was no runoff from snowmelt at this location. (SWC 2-d2)

The largest storm runoff peaks in the 4-year history of the project were observed on 7 of the 10 tributaries in the study reach of the Washita River Basin at Chickasha, Oklahoma. The significance of their magnitude cannot be determined until a longer period of record has been accumulated. However, the influence of watershed size on storm runoff is evident in that the larger the watershed, the smaller the unit runoff rate. (SWC 2-e3)

Not only the total runoff, but runoff peak rates on the Walnut Gulch Experimental Watershed are often affected by channel abstractions. Though peak rates may not be reduced proportionately (depending mainly on the sequence of flows), the expectancy of high peaks is materially affected in relation to size of the drainage area. This effect, combined also with limited areal coverage of convective storms: (1) Makes peak floods from small drainages very high in comparison to those from larger watersheds; (2) reduces the significance of watershed size (over a few square miles) as a determinant of the magnitude of flood peaks; and (3) so increases the variability of annual flood peaks as to render the "freak" flood much more probable and, projecting from short-term records, much more hazardous in the Southwest than in humid areas of the country. It is notable that a peak runoff rate of 2.44 inches per hour (5,030 c.f.s.) was measured in 1964 from a 3.2-square-mile dominantly grass-covered subwatershed of the Walnut Gulch Watershed. The storm was about a 25-year probability event, squarely centered over this watershed. The same storm extended, in runoff-producing proportions also, over a watershed area of 6.0 square miles measured further downstream. The peak runoff rate of this larger area was only 1.10 inches per hour and its actual flood peak was less than for the smaller watershed. (SWC 2-g2)

2. Dynamics of channel flow. Flood routing computations are often hindered by apparent reductions in average velocity as flow increases from in-bank to out-of-bank stages. This is partly due to stagnation in immediate areas of channel boundaries. The Hydrograph Laboratory at Beltsville, Maryland, has undertaken a study of the feasibility of reconstituting an equation of uniform flow which will remove cross sections of stagnant water from the computations of average velocity. Using data published by Ree and Palmer at the ARS Outdoor Hydraulic Laboratory at Stillwater, Oklahoma, the following tentative equation was derived for uniform flow by evaluating the loss of momentum of the fluid when theoretically passing from a frictionless channel into a channel with surface roughness: $V = C_r\sqrt{(A-A_s)\,S_f}$; where, V is velocity in feet per second, A is area of flow in square feet, A_s is area of stagnation in square feet, S_f is friction slope in feet per foot, and C_r is retardance coefficient in l:sec. This equation applied very well to uniform flow data above some small depth. Below this depth, a nearly stagnant flow condition existed. This depth of stagnation varied with the condition of the channel roughness. Trial applications of this new equation to natural streams are intended. If the feasibility of this new equation can be substantiated, it will help to eliminate decreases encountered in the computed fluid conveyance characteristics of a natural channel as flow proceeds out-of-bank. (SWC 2-aD1)

A program developed by the U. S. Army Corps of Engineers for computing water surface profiles by the step method was modified in the Hydrograph Laboratory at Beltsville, Maryland, to spatially vary flow concordantly with drainage area in order to provide required water surface profiles for selected flows per unit area. Spatial variations in flow, and drastic

differences in cross sections of the upland watershed streams used for trial runs, caused the computed profiles to undulate unrealistically. A review of results indicated that undulations were greatest in reaches having steep slopes. As a result, the program was further modified to interpolate hydraulic elements for theoretical cross sections at predetermined vertical intervals as needed between surveyed cross sections. Spatial variation of flow was also graduated by interpolating flow at these theoretical cross sections in the ratio of the accumulative interval to the total interval of elevation. By these means the water surface profiles were stabilized in close conformity with profiles computed at much greater cost by more sophisticated techniques. This program has been incorporated into the mathematical model of watershed performance in the Hydrograph Laboratory and is also being incorporated into the hydraulic and economic evaluation sub-programs of the Soil Conservation Service comprehensive IBM 7094 computations for project formulation. These programs enable SCS to plan a greater number of projects and to make more exhaustive investigations for maximizing the benefits of each watershed plan. (SWC 2-aD1)

Over 100 cross sections on the channel system of the 330-acre experimental watershed (W-1) at Fennimore, Wisconsin, were obtained for use in flood routing studies. The three subwatersheds W-2, W-3, and W-4 provide inflow hydrographs which are routed through the subsequent channel system for comparison with observed outflow at station W-1. Water surface profiles have been computed by the Hydrograph Laboratory for a range of assumed flows, and storage indication curves have been derived for various reaches of the channel system. Several storms have been routed with acceptable accuracy. However, the intent is to study trends resulting from variations in tabulation and computation intervals, reach lengths, retardance coefficients, energy considerations, infiltration capacities and other factors affecting the hydrograph. It is hoped that the detailed hydrologic records kept at Fennimore will provide the needed checks for improving flood routing techniques in general. (SWC 2-aD1)

A program was developed by the Hydrograph Laboratory for an IBM 1620 computer with a 40 K storage capacity, for the simultaneous solution of the equations of motion and continuity of mass in calculating flood wave propagation. To cut down running time on large problems, an implicit numerical method was used in solving the equations. The program is generally functional and has been used successfully in a number of flood routing problems. A report is in preparation that presents the program and a number of examples illustrating the influence of the downstream cross sections, the shape of the inflow hydrograph, and the inflows at confluences. (SWC 2-aD1)

An IBM 1620 program utilizing the complete equation of motion was also developed by the Hydrograph Laboratory, and is functioning for problems involving only a few reaches; however, more testing is needed to establish its usefulness. Both programs were used to complete a comparison of early flood routing methods made by Thomas. Combinations of reach length $\Delta x = 25$ and 50 miles and time increment $\Delta t = 12$, 24, and 48 hours were tested.

Some of the conclusions reached by Thomas with partial results do not appear to be completely verifiable. The routing methods tested, including storage routing, are affected by choices of Δx and Δt. This example could not have been extended with explicit methods; however, no difficulty was experienced with the implicit method developed in this study. (SWC 2-aD1)

Analysis of hydraulic data for stream cross sections on the Sleepers River Experimental Watershed at Danville, Vermont, indicate that the stage-discharge relation is identical for both the rising and falling limbs of hydrographs. Thus, a loop-rating curve does not appear to exist in these steep, boulder-strewn mountain channels. The loop rating occurs most frequently in channels with a mild slope and where there is a relatively long distance upstream from a critical depth section. In rough mountain streams, the distance between critical flow sections varies with discharge, but there are seldom sufficiently long reaches between the cross sections for the occurrence of a loop rating. (SWC 2-a3)

A new duplex weir was constructed in Danville, Vermont, at the confluence of two streams in the Sleepers River Experimental Watershed to provide runoff measurements from watersheds of 0.40 square miles and 1.43 square miles. The runoff from the combined watersheds of 1.83 square miles will be determined from a computer program. The runoff from the 1.43-square-mile watershed is measured by a 5:1 broadcrested V-notch weir in series with a 90-degree sharp-crested weir for low-flow measurement. A two-pen recorder traces the stage-height record for these two weirs. A 4-foot-deep 90-degree broadcrested V-notch weir measures the runoff from the 0.40-square-mile watershed. The stilling wells and a 70-foot wall separates the two streams. Economies are realized from the convenience of maintenance and heating of the installations and by obtaining records for three watersheds at considerably less costs with one structure than the costs would be for three separate structures. (SWC 2-a3)

3. Hydrograph synthesis. An equation was derived by the Hydrograph Laboratory at Beltsville, Maryland, that permits derivations of multiple peaked hydrographs directly from rainfall excess without the tedious labor of deriving and summing hydrographs from successive storm increments. Results indicate that if good estimates of rainfall excess are available, two successive routings through partial storage will induce the storage-flow hysteresis needed to synthesize the hydrograph. The infiltration capacity of soils, and particularly the recovery of infiltration capacity during intervening periods of little or no rainfall, is of prime importance in this technique. Research is needed to refine estimates of rainfall excess either as a residual after subtracting infiltration capacity of the soil or as a rainfall-runoff relationship imposing a new initial abstraction after each period of low-intensity rainfall. Research is also needed to develop equations and parameters for the prediction of the recession constant from measurable characteristics or conditions on a watershed. These two studies have a high priority in the order of studies anticipated for the Hydrograph Laboratory as facilities become available. (SWC 2-aD1)

At Chickasha, Oklahoma, watershed factors found related to storm runoff include drainage area size and average width, length of channel to a point opposite the centroid, and the geology. These factors have been determined for 70 subwatersheds of the Washita River Basin study area and will be related to the precipitation experience for 1941 to 1950 to reproduce the regimen of flows in the Washita River for this same period. The flood routing procedure that produces the best fit will be used in subsequent analyses as one of the methods to assess the effects of flood abatement structures installed in the basin. (SWC 2-e3)

G. Watershed Models

1. Digital model. A model was developed at the Sedimentation Laboratory, and programmed for the IBM 1620 computer, for predicting the long-term rainfall-runoff relationships for a 3-acre pasture watershed in which the variables provided from three years of concomitant data on the watershed were: (1) Precipitation; (2) the amount of precipitation retained before runoff begins; (3) potential storage for daily rainfall retention following the initiation of runoff; (4) runoff; and (5) a constant called k. Daily values of the other terms necessary to solve the water balance equation, i.e., potential evapotranspiration; percolation to ground water; available soil moisture in each storage reservoir in the soil profile; antecedent soil moisture; and the total soil moisture were either measured or calculated. Daily runoff was computed for the 28-year period (1935-62) from daily values of temperature and precipitation. The computed average yearly runoff for the 28 years was 20.16 inches in contrast to average observed runoff of 16.39 inches for the 3 years (1959-61) used in deriving the model. The computed runoff for the same three years departed from the observed values by only 0.03 inch. (SWC 2-b3)

2. Sevier River Basin electronic analog. Following the recommendations resulting from a joint feasibility study by the Agricultural Research Service and Utah State University in 1963, a complex electronic analog simulator was developed in the past year for the Soil Conservation Service and the State of Utah, for hydrologic planning studies of the Sevier River Basin in Utah. Detailed design and development was accomplished by staff of the Utah State Water Resources Laboratory, with ARS continuing to serve as consultant on the project. It has been possible to build the Sevier Basin simulator essentially from basic computer sub-assemblies and recording equipment originally acquired and later obsolete in the U. S. missile and space probe programs. The simulator is now in regular use by the SCS Basin Planning Survey Party, and is understood to be very substantially facilitating their work. It accelerates and permits more thorough investigations for optimizing basin water resource development plans. This simulator development is a pioneering accomplishment in that it not only incorporates capability for representing a basin's ground water situation, but also major aspects of its surface water hydrology, and the interrelations between its surface and ground water resources. Such processes as snowmelt, ground water storage

and outflows, streamflow and diversions, reservoir operation, consumptive use of water by crops and natural vegetation can be simulated. Thus, the movement of water can be traced from its source in the mountains, through the Sevier Basin, until it is either used or returns to the stream and ground water for reuse. Downstream results of alternative upstream conservation and water-use programs can be studied, and can be demonstrated on the analog for the information of various interests. (SWC 2-g3)

3. Physical model. The scale model of a field study watershed, and convective thunderstorm simulator completed at Logan, Utah, in cooperation with Utah State University in 1963, was improved in 1964 with respect to mechanical durability of pump-motor assemblies, control of the precipitation input, and the measurement and recording of the runoff. Equipment calibrations were refined in the past year, and studies carried out to generally evaluate capability of the model system to reproduce known behavior of the prototype. Current study is on effects of varied mechanical properties of the precipitation fluid, in reaction to those of the surface of the watershed model, to determine the most suitable fluid (or fluids) for use in subsequent studies. This first phase of experimentation, with a basic problem of hydraulic similitudes involved in utilization of watershed scale models, is scheduled for completion around mid-1965. (SWC 2-g2)

H. Hydrologic Data Releases

The compilation and publication of selected hydrologic data for all Agricultural Research Service experimental agricultural watersheds is a continuing effort. USDA Miscellaneous Publication No. 994 for 1960-61 data is now available. Work on hydrologic data sheets for years 1962, 1963 and 1964 is progressing. It is planned that the 1962 hydrologic data will be submitted for publication in November 1965, with data for 1963 and 1964 to be submitted subsequently at six-month intervals. The hydrologic data consist of: Monthly precipitation and runoff; annual maximum discharges and annual maximum runoff volumes for various durations from 1 hour to 8 days; daily precipitation, air temperature and discharge for the larger experimental watersheds; tabular data and graphs for selected runoff events; description of various watershed characteristics; and topographical, geological and isohyetal maps. (SWC 2)

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AREA 3: HYDRAULICS OF IRRIGATION, DRAINAGE, AND WATERSHED STRUCTURES, CHANNELS AND FACILITIES

Problem. Water control structures of various types represent the largest part of the public and private cost for watershed protection and development programs. They are also essential, and expensive, features for irrigation and drainage developments. Research on the hydraulic design of water control structures will reduce the possibilities of overdesign, which increases the costs unjustifiably, or underdesign, which may result in costly failure. All items of costs not required for safe functioning of structures must be eliminated.

Development of new concepts in the geometry of spillways, drop structures, and stilling basins at pipe outlets and below overfall structures are included in this research. Other studies include development of new and improved devices for control of floating debris and vortices at the entrance to closed conduit spillways; investigations of energy losses associated with various components of water control structures, hydraulic jumps, the dynamics of overland flow and flood wave velocities and energy gradients in channels of various roughnesses; and development of improved flumes, weirs, gates, and rating sections for streamflow and water discharge measurement. The hydraulic properties of various grasses and other vegetation in water channels are also determined and the effectiveness of mats and mulching materials as an aid in the establishment of grass-lined channels and waterways are tested and evaluated.

It is not possible nor desirable to model the many hundreds of agriculture-related water control structures built each year, as is the usual custom with the larger dams and spillways on the main river systems. This research, instead, seeks to establish principles and develop dimensionless designs which can be adapted to various site situations and size requirements on individual farms and ranches and in upstream watersheds.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program in which hydraulic and agricultural engineers are engaged in both basic and applied research on the hydraulic performance and engineering design of water control structures and channels. The studies are oriented primarily to provide information relating to the types of structures and channels involved in group irrigation, drainage and watershed protection activities.

The scientific effort devoted to this area of research totals 7.0 man-years in the reporting period. Of this number 1.1 are devoted to basic studies of hydraulic phenomena; 4.4 to criteria for hydraulic design of water control structures; 0.5 to hydraulics of waterways and vegetative channels; and 1.0 to flow measurements and water metering devices.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in research on the hydraulics of irrigation, drainage, and watershed facilities. Basic studies are being made on the energy conversion mechanisms in incompressible fluid flow. Improved hydraulic design is being studied for erosion control and drainage structures.

Studies are also being made on the hydraulics of subcritical flow in small, rough channels; hydraulics of irrigation by surface flooding methods; and the effects of channel hydraulics on the runoff hydrograph. Part of the effort in Western regional research project W-65 is directed to this activity. Methods of measuring irrigation water are also being studied.

The total research effort in hydraulics at the State experiment stations is 5 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Basic Studies of Hydraulic Phenomena

1. Effect of crest thickness of hood drop inlet on crest loss coefficient. Tests of the hood drop inlet at St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, have shown that the crest thickness does not affect the crest loss coefficient. This is opposite to the finding for the two-way drop inlet. The finding will significantly reduce the number of tests required to evaluate the hood drop inlets. Furthermore, the design of hood drop inlets will be simpler and more economical. (SWC 3-c1)

2. Spatially varied flow. At Stillwater, Oklahoma, studies of spatially varied flow in an open channel show that the water surface profile can be predicted with accuracy if the appropriate constants for the momentum equation are used. Tests on a 400-foot-long grassed channel which received a steady inflow all along its length show good agreement between observed and calculated profiles. The momentum coefficient for the test channel was found to be 1.56. This is significantly higher than the value, 1.0, generally assumed in the solution of channel flow problems. The findings in these studies are directly applicable to improvement of the design of terraces and diversion channels. (SWC 3-e1)

B. Criteria for Hydraulic Design of Water Control Structures

1. Effect of size and location of low-stage orifice in two-way drop inlet on priming spillway. Hydraulic laboratory tests of models of two-way drop inlets at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, revealed that the poor performance of the low-stage orifice in the end walls was due to the issuing jet occupying the full width of the drop inlet. This prevents aeration of the space under the nappe, causes a fluctuating nappe and excessive disturbance in the drop inlet, and can prevent the spillway from priming. The simple solution discovered is to reduce the width of the orifice to three-fourths or less the width of the drop inlet. This permits aeration of the nappe undersurface and assures dependable performance of the spillway. The tests of the low-stage orifices show that the orifice(s) can be located at any elevation in the drop inlet or in either or both end walls. This will permit the designer to establish the permanent pool level of the reservoir at the most suitable elevation for each installation. (SWC 3-c1)

2. Design equations for energy loss in two-way drop inlets. At the St. Anthony Falls Hydraulic Laboratory, design equations were developed and tested for the two-way inlet crest energy loss, the transition energy loss, and the total entrance energy loss. This will permit the ready preparation of computer programs for use in the design of the hydraulic capacity of two-way drop inlets. The crest loss coefficient equation indicates the effects of antivortex plate height, crest thickness, and drop inlet length. The transition loss coefficient includes the effects of drop inlet length, barrel slope, and type of barrel entrance. The entrance loss coefficient combines the effects of the crest and transition losses. This analytical separation and later recombination of entrance losses conserves experimental work and increases the range of usefulness of the results. Partial success has been achieved in the reduction to a common equation of the pressure data obtained for the two-way drop inlet. Complete success will permit the use of this equation to prepare computer programs. These programs will speed up the structural design of the two-way drop inlets, as well as providing for testing for the possibility that damaging cavitation pressures may exist. (SWC 3-c1)

3. Effect of pipe slope and thickness on entrance loss coefficient of the hood drop inlet. Further model tests of the hood drop inlet at the St. Anthony Falls Hydraulic Laboratory showed that its entrance loss coefficient decreased as the barrel slope increases, as the thin wall barrel increases in thickness, and as the size of the drop inlet increases. These findings will assist the designer in determining the optimum proportions of the drop inlet. (SWC 3-c1)

4. Effect of trash rack on spillway capacity. At the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma, trash accumulated on a trash rack placed on or near the crest of a drop inlet spillway and reduced spillway capacity. An improved trash rack mounted outside the high-velocity flow region in the vicinity of the spillway entrance and equipped with full skirts or side panels did not reduce spillway capacity significantly when subjected to similar trash tests. The skirt prevents floating trash from entering the drop inlet during flow in the weir control range, thus contributing to the efficient operation and safety of the structure.

5. Friction loss in pipe. At Stillwater, Oklahoma, laboratory friction loss studies were conducted on helical corrugated steel pipe, widely used in the principal spillway of upstream structures. The position of the hydraulic grade line at the exit of a freely discharging helical corrugated pipe was found to be much lower than for standard corrugated or concrete pipe. This finding is of particular importance in low head pipe spillway design. The use of the midpoint of the pipe at the exit for calculating the grade line can lead to relatively large underestimates of the capacity of helical corrugated pipe structures. (SWC 3-e2)

C. Hydraulics of Waterways and Vegetative Channels

At Tombstone, Arizona, field studies of the hydraulics of sediment-laden runoff moving through watershed channel systems continue to indicate the importance of translatory waves or surges to the magnitude and timing of flood peaks, especially those associated with cloudburst-type storms. A storm on July 22, 1964 produced an abrupt translatory wave in the channel reach between two runoff measuring stations, the first such vertical flow front actually seen on the Walnut Gulch Experimental Watershed. Velocity of the 1.1- to 1.3-foot-high wave front moving on a dry streambed was 6.4 feet per second. A similar wave moving on a wet bed, on September 9, had a velocity of 7.9 feet per second. The velocity of wave fronts traveling over these alluvial streambeds appears to be relatively independent of the discharge, but apparently to be more dependent on the moisture content of the alluvium. This phenomena introduces another complicating factor in traditional methods of flood routing. (SWC 3-g1)

D. Flow Measurement and Water-Metering Devices

At Stillwater, Oklahoma, model studies developed satisfactory flow rate measuring flumes for two sites in the Walnut Gulch Experimental Watershed. The flows in Walnut Gulch are flashy and heavily laden with sediment and the channel slopes are steep. A special type of flume, now known as the Tombstone flume, is needed to obtain a measurement under these conditions. It was found that approach conditions affect the performance of the flume and individual model tests are needed for each location. At Site No. 8 a change in the alignment of the approach channel caused standing waves in the flume. It was found that these could be eliminated with an upstream jetty. At Site No. 5 the approach flow was relatively tranquil and the flume performed well without special baffling devices. (SWC 3-e1)

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AREA 4: CONSERVATION OF WATER SUPPLIES FOR AGRICULTURAL USE

Problem. The increased competition agriculture is facing from industry and domestic users for a limited water supply requires the development of new sources of farm supply as well as increased efficiency in the collection, storage, conveyance, and use of existing supplies.

About 76,000,000 acre-feet of water is lost to the irrigating farmer, largely through seepage, evaporation, use by nonbeneficial plants, and wasteful runoff during irrigation.

Falling water tables resulting from withdrawals exceeding recharge are increasing pumping costs and the danger of depleting the supply over an appreciable area.

The conversion of cropland to grazing land requires an adequate livestock water supply strategically located to preserve the newly developed pastures. This is also acritical problem on many established dryland grazing areas. The rapidly increasing use of farm chemicals poses a potential threat to the quality of water moving off of or through the soil of farm fields. Knowledge of the mechanics involved and the magnitude of the threat is needed so the development of management methods to prevent contamination of urgently needed water supplies can move forward without delay.

Many acre-feet of water are transpired by vegetation of noneconomic value. Replacement with vegetation of economic value would greatly benefit the rangeland areas.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of water conservation, utilizing agricultural and hydraulic engineers, soil physicists and chemists, and geologists. The work is in progress at the U. S. Water Conservation Laboratory, Tempe, Arizona, and at physiographic area research centers and field stations throughout the United States. In addition, three PL-480 projects on water conservation are in progress in Israel. The scientific and engineering effort in this area totals 27 professional man-years per year. Of this total, 8.6 are devoted to control of seepage and suppression of evaporation from surfaces; 8.1 to farm water supplies, structures and water measurement; 8.2 to methods, practices and devices for ground water recharge; and 2.1 to wasted and contaminated waters.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are conducting research on the conservation of water supplies. These studies seek to make better use of available water supplies through reuse, by reducing unnecessary seepage losses in storage and conveyance structures, and by limiting evaporation losses from soil, plant and water surfaces.

The total research effort in conservation of water supplies at the State experiment stations is 5 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Control of Seepage and Suppression of Evaporation from Surfaces

1. Seepage. Seepage from storage and conveyance structures represents a loss to the immediate farmer even though the seepage water moves to the ground water for future recovery by pumping. When seepage causes high water tables, drainage and sometimes salinity problems are created.

Several low-cost, sprayable crack sealers were developed at the U. S. Water Conservation Laboratory and applied to cracks in concrete ditches and a concrete canal with apparent success. Conventional crack sealers require extensive preparation work on the crack before application and the combined costs of materials and application are high. Materials costs have been reduced by using modified asphalt compounds formulated to provide ductility, durability, and bonding to concrete that has received minimal preparation. Application costs have been reduced by the use of spray techniques. Observations eight months after application indicate that the new materials are performing satisfactorily.

A low-cost water-borne sealant developed through research at the U. S. Water Conservation Laboratory, Tempe, Arizona, has consistently reduced seepage by more than 90 percent in laboratory tests, regardless of initial seepage rate. The sealant is a petroleum emulsion which can be added to the water in a canal or reservoir and reduces seepage by mechanically plugging the soil pores. Emulsion stability, initial seepage rate, soil structure, water temperature, and other related factors have been found to influence the effectiveness of such sealants. This new emulsion appears to solve these problems except that of soil structure. Additional testing is necessary to determine which soils can be successfully treated. (SWC 4-gG1)

Acid colloid treatment imparted little rot resistance to either cotton or jute for canal liners in tests made at Logan, Utah. Of the membrane tested, cured butyl continues to be the most resistant to degradation when exposed to the weather. Butyl, polyisobutylene, and ethylene propylene rubber sheet structures bonded to concrete specimens retained an excellent bond after more than 1,000 freeze-thaw cycles. Butyl latex, when added to

concrete mixes, acted as an air-entraining agent and imparted approximately the same frost protection provided by commercial air-entraining agents. (SWC 4-g3)

A study at Reno, Nevada, of the chemical and physical properties of high swell bentonites has shown that flocculating bentonites are the poorest sealers and that deflocculating bentonites are by far the best sealers. Besides flocculation, silt content, clay content, volume of swell, viscosity, exchangeable sodium, and gel strength account for the other variations in water movement through high swell bentonites. As the silt content increased, water movement increased, but as the magnitude of the other properties increased, water movement decreased. Flocculation appears to be a simple, fast, and reliable criterion for rating the sealing potential of bentonites. (SWC 4-g3)

One to five drying and wetting cycles have destroyed seals formed by sedimentation of bentonite suspensions. Differences depended on the quality of the bentonite and water and the type of soil involved. Covering the seal with 6 inches of soil prevented drying in the arid western Nevada climate. Two-year-old buried seals, currently under test in the field, seep between .007 and .13 foot of water per day. These seals are of two types; a pure membrane of bentonite, and a blanket of bentonite-soil mix. (SWC 4-g3)

Calculation of water movement in unsaturated soil has been greatly simplified by recent work at the U. S. Water Conservation Laboratory. Computation has previously been difficult because the hydraulic conductivity decreases continuously as the soil-water pressure becomes more negative. The simplification consists of replacing the actual zone of negative pressure by a fictitious zone with a constant conductivity equal to that at saturation. The thickness of the zone is determined by the so-called "critical pressure", obtained by graphical integration from the pressure-conductivity relation. This simplified treatment appears to accurately account for the unsaturated flow for a number of types of subsurface flow systems. Typical critical pressure values have been determined for a number of soils for which data were available in the literature. Laboratory studies have shown that the critical pressure can be estimated by the pressure at which air begins to displace water and bubble through the soil pores. This finding opens the way for evaluating critical pressure directly in the field. (SWC 4-gG1)

2. Evaporation from soil and plant surfaces. Micrometeorological data can be used to compute evaporation from crop and soil surfaces for short periods (15 minutes or longer) by the gradient Bowen ratio method, using differences in air temperature and vapor pressure measured at 5 cm. and at 40 cm. above the surface. The results of field tests at the U. S. Water Conservation Laboratory indicate that the relative errors in estimating evaporation were less than 5 percent for daylight periods. Evapotranspiration calculated from soil moisture depletion data appeared to be more

erratic than evapotranspiration calculated from meteorological data. Frequent and sometimes excessive irrigation tended to increase the deep percolation losses, which caused some error in soil moisture depletion measurements. (SWC 4-gG2)

Research at the U. S. Water Conservation Laboratory has shown that there is no great difference in the amount of solar radiation reflected by fully developed and healthy field crops. Broadleaf plants tend to reflect slightly more solar radiation than grasses. These studies showed that the net radiation, or radiation absorbed by the crop cover, can be estimated from solar radiation on an average summer day with an error of less than 10 percent. This finding is useful in estimating evapotranspiration from irrigated crops. (SWC 4-gG2)

Studies at the U. S. Water Conservation Laboratory have shown that water movement in dry soils occurs in both the liquid and vapor phases. Measurements made on soils with moisture contents ranging from nearly 0 to 5 percent by weight showed that for coarse-textured soils, almost all water movement occurred as vapor diffusion. Liquid diffusion was negligible, but in fine-textured soils, liquid diffusion was not negligible. At 2 percent moisture content, more than 10 percent of the water movement in Adelanto loam occurred in the liquid phase. The importance of temperature on water movement in dry soils was also demonstrated. Total moisture movement rates changed eight- to ten-fold during temperature changes of only 30°C. (SWC 4-gG4)

3. Evaporation from water surfaces. A new method was developed at the U. S. Water Conservation Laboratory for continuously applying evaporation retardants to a water surface without using any mechanical devices. Discrete particles of long-chain alkanols, such as hexadecanol and octadecanol, were dispersed in a water-soluble matrix and were released as the matrix dissolved when placed in water. Several saccharides, including corn syrup and hydroxyethyl cellulose, proved satisfactory as matrix materials. The rate of producing evaporation-retarding films on the water surface was controlled by varying the rate at which alkanol particles were released from the soluble matrix. This was accomplished by varying both the matrix-alkanol formulation and the area of material exposed to the water. A small vial of matrix-alkanol material, suspended from a float, reduced evaporation from a large outdoor tank by 40 percent for a 2-week period. (SWC 4-gG2)

B. Farm Water Supplies, Structures, and Water Measurement

1. Water harvest. At Tifton, Georgia, the study to provide information for use in determining optimum storage volume and other pond design criteria for utilization of available farm water supplies on Coastal Plain soils again showed that a large proportion of the flow to the pond was from subsurface water movement and that a large portion of this flow was discharged through the pond spillway. Pond volume is equal to a little

less than 2 inches runoff from the 60-acre loamy sand watershed. These early records imply a low storage volume to drainage area ratios that could result in inadequate retention of water when the supply is abundant for use in times of drought when runoff could be drastically reduced. (SWC 4-b1)

At McCredie, Missouri, 1964 runoff totaling 14.8 acre-feet from a 154-acre claypan watershed was the third lowest since observations began in 1941. The lowest amount of runoff, totaling 2.7 acre-feet, was observed in both 1954 and 1963. Runoff in 1964 with precipitation direct to the reservoir and storage from previous years was enough to offset seepage and evaporation losses and provide for an irrigation need of 8 inches of water for 68 acres of cropland. Reservoir volume is equal to 7 inches runoff from the watershed. (SWC 4-c1)

Field installations of sprayed asphalt pavements, constructed by the U. S. Water Conservation Laboratory for water harvesting, were found to have penetration resistance remarkably similar to that measured on the same treatments applied to soil trays in the laboratory. Pavements in the field were tested with a portable testing machine designed to have the same loading characteristics as the laboratory testing machine. Penetration resistance was measured by the force required to press a blunt probe with a cross section area of 6.45 $cm.^2$ into the pavement. Average penetration resistances of three different field treatments were 76.0, 41.4, and 16.4 $kg./cm.^2$. Average laboratory results for these same treatments were 65.5, 43.8, and 17.8 $kg./cm.^2$. These results indicate that properly conducted laboratory tests can be used to accurately evaluate materials and application rates for field installation of sprayed asphalt pavements. (SWC 4-gG3)

Wind damage to rainfall catchments built of low-cost plastic sheeting can be prevented by bonding the plastic to the soil with asphalt. Investigations at the U. S. Water Conservation Laboratory have shown that several types of commercially available asphalt emulsions can be used to glue 1.5-mil polyethylene to the soil. The force required to lift the film from the soil exceeded 0.5 $kg./cm.^2$ which was the maximum capacity of the testing machine. This bond strength far exceeds any uplift force which might be caused by wind. These tests show that thin plastic films, costing 3 cents per square yard, can be bonded to the soil with inexpensive asphalt to construct low-cost water harvesting aprons. (SWC 4-gG3)

At Logan, Utah, a recently developed two-piece bag offers an opportunity for reducing the cost of the storage structure through the use of a less costly material, such as vinyl for the bottom section, rather than butyl. The rain trap type of water harvest installations are now in use in Hawaii, Colorado, Wyoming, Utah, Arizona, Nevada, and California. (SWC 4-g3)

2. Water measurement and control structures. Improved on-farm irrigation structures that combine water control and measurement are needed for economic and efficient application of water. At Fort Collins, Colorado, two overflow weirs that are an integral part of a sliding gate to control water level in a farm ditch were evaluated. One weir, similar to the so-called Romijn weir developed in Europe, was found suitable for combined control and measurement. The calibration curve remained constant over a wide range of weir elevations and was not affected by submergences up to 70 percent. The combination weir and gate should provide more economical water control and measurement than many devices in current use on irrigated farms in the United States. (SWC 4-3(d1)Rev.)

At Twin Falls, Idaho, an analysis of submerged flow data resulted in a simplified procedure for determining accurate discharge measurements with a Parshall measuring flume operating under submerged conditions. The method is much simpler to use than previous methods and the accuracy is comparable. It is needed for submergence greater than 60 percent for the smaller flumes and 80 percent for the larger flumes. (SWC 5-f2)

An improved empirical discharge equation for uncalibrated commercial pipe elbows used as flow meters was developed at the U. S. Water Conservation Laboratory. The equation is used to calculate flow of water through the elbow from a measurement of the difference in pressure on the inside and outside of the elbow bend. Calculated flow rates were accurate within $\pm$ 5 percent of actual flow rates for elbows ranging from 3 to 12 inches in diameter. This accuracy was achieved with no measurement of the pipe elbow other than the inside diameter. A simple method for measuring the elbow bend radius with a plaster mold was also developed. When both inside diameter and bend radius measurements were made, the accuracy was increased to within $\pm$ 3 percent of actual flow rates. (SWC 4-gG5)

3. Runoff water management. Conservation bench terrace studies were continued at Bushland, Texas; Mandan, North Dakota; Newell, South Dakota; Sidney, Montana; and Akron, Colorado. No new trends were observed during 1964. The studies at Big Spring, Texas, on Amarillo fine sandy loam have been discontinued as the results during the 4-year period, 1960-1963, indicated the practice was not effective on this soil, largely because of the high permeability of the soil. (SWC 4-13(e2))

C. Methods, Practices and Devices for Ground Water Recharge

At Bushland, Texas, tests on low-cost techniques for injecting recharge water into water-bearing strata have resulted in two methods that have considerable promise. One method consists of drilling a shaft, 30 inches in diameter, nearly 100 feet deep into 35 feet of aquifer material and terminating 55 feet above the water table. The shaft is backfilled with gravel. When the shaft was tested for intake capacity with clear water, the recharge rate was 112 g.p.m.; however, excessive head loss in the gravel backfill indicated that the construction method limited recharge rate.

A 6-inch-diameter observation well screened through 90 percent of the saturated aquifer (100 feet of screen) recharged over 1,000 g.p.m. for a few hours, and declined to 500 g.p.m. after three days. It is concluded that small diameter wells are especially promising as an economical method of recharging clean water into the aquifer. (SWC 4-13(e2))

At Fresno, California, physical tests of soil cores obtained from field borings in an area having a subsurface impeding layer showed a lowering of permeabilities with an increase in fine grain size as expected, but that bulk density values could not be used to predict permeability. Sulfate analysis revealed a high concentration of gypsum just above an impeding layer causing a perched water table. This gypsum usually appears as small crystals and gives a rather poorly developed veined appearance to the soil core.

Laboratory studies with layered systems composed of different grain sizes indicated positive pressures occurred near the top of the layered column and negative pressures developed with depth, reaching a maximum at or near the layer interface. Then a zone of unit gradient occurred followed by a zone where tensions decreased, approaching zero (atmospheric) at the column base. There was no significant hydraulic head loss at the interface for the grain sizes studied. Drainage rate curves for the layered system were not continuous power functions. When sufficient tensions developed, prior to the dissipation of the surface head, water was removed from storage in the coarser sand layers causing the discharge to remain constant for a short time.

Field checks at Fresno, California, indicate that a reasonable approximation of the maximum height of a ground water mound under a recharge area can be obtained by electrical analog models and Glover's mathematical prediction equation, provided (1) the correct flow assumptions are determined relative to the flow conditions encountered during recharge, (2) a well test is run, and (3) the long-time intake rate can be estimated over the area flooded. Neither the analog nor the mathematical model predicted the observed field shape of the rising ground water mound. The field tests indicate this may be due to the absence of air displacement beneath the plot as the wet front advances to the water table. (SWC 4-g2)

Investigations at the U. S. Water Conservation Laboratory, combining mathematical analysis and electrical analog models to predict the rate of ground water mound rise have shown that errors due to commonly used assumptions, that flow within the mound is horizontal and that the flow above the water table can be neglected, are small as the mound begins to develop but become larger as buildup of the mound progresses. These studies indicate the desirability of using electrical analog models for analyzing ground water mound problems in place of mathematical procedures which include erroneous assumptions. (SWC 4-gG3)

The use of tritium levels to determine flow velocity of ground water recharging deep confined aquifers in the San Joaquin Valley of California was investigated at Fresno, California. Peak tritium concentrations of the rain and snow in the Northern Hemisphere as a result of Castle Weapons tests in 1954 and those associated with nuclear testing in 1958 and 1961 were used as sources. Sampling of numerous wells in the San Joaquin Valley permitted the location of the tritium fronts and the calculation of the velocity of ground water moving across the valley to be 34 feet per day along a northern traverse line of wells and 40 feet per day along a southern traverse line. Calculated permeabilities based on average gradients and the above velocities are 10,000 and 10,800 ft./ft.^{2}/day. This method gives maximum velocities and permeabilities. The study also indicated areas of recharge to the confined aquifers of western Fresno County with the relative magnitudes of recharge indicated. (SWC 4-g2)

In a PL-480 project, Removal of Suspended Matter and Turbidity from Water by Flocculation with Polyelectrolyte Coagulants and Coagulation Acids, at the Israel Institute of Technology, both cationic polyelectrolytes and anionic polymers are being prepared for use in the study. In flocculation experiments the doses of polyamines required for clarification of kaolinite suspensions were one-half or less those required for montmorillonite. The sodium montmorillonite required much greater doses for flocculation than when the mineral was in the calcium form. Work is beginning on flocculation with anionic polymers. A method has been found for measuring the residuals of the cationic polyelectrolyte down to 0.1 m./liter. (A10-SWC-25)

D. Wasted and Contaminated Waters

1. Chemical water contamination mechanics and control. Pesticide materials are used widely in urban, industrial, and rural areas. Information is urgently needed on the loss of pesticide materials from agricultural lands following their application on farm crops. Preliminary results from a study with 2-4 dichlorophenoxyacetic acid (2,4-D) at Watkinsville, Georgia, show that losses of this compound in washoff (water + soil) are related to its chemical composition, the time interval between application and occurrence of rainfall, and soil moisture at time of application. When an excessive-rate rainstorm was applied at 2-1/2 inches per hour for 2 hours with the rainfall simulator, 1 hour after 2,4-D was sprayed on dry, bare soil (as in a pre-emergence application), losses in the washoff for the ester and the amine forms ranged from 4.4 and 1.3 p.p.m., respectively, during the last 30 minutes of the storm. When the rain was applied 48 or 96 hours after application of the material, the losses of the amine were less than one-half those measured when rain was applied at 1 hour. Losses were somewhat greater in all cases when the chemical was applied to wet soil. The bioassay method was used in these studies, with cucumber roots as the test plant. The studies are being continued and expanded. (SWC 4-14(b2))

A field study involving intrusion of sea water into a fresh water lagoon at the mouth of the Salinas River in California, revealed a small average gradient from the sea to the lagoon, although the tidal fluctuations were above and below the lagoon water elevation. This, together with the different densities of sea and fresh water, was determined to be sufficient to cause a high salinity buildup in the lagoon during the summer and early fall months. A proposal by local people to raise a sand bar so as to prevent overtopping during high tides and storms was shown to be infeasible as far as preventing sea water intrusion, because the major intrusion resulted from underflow. This study was made at the request of the Soil Conservation Service. The Salinas River is typical of many streams flowing into the Pacific Ocean along the California coast. (SWC 4-g1)

At Newell, in western South Dakota, seasonal fluctuations in the salt concentrations of 18 stockwater ponds were measured. Salt content of the ponds varied with the frequency and amount of runoff, and ranged from 100 p.p.m. to nearly 3,000 p.p.m. Seven of the ponds had water of excellent quality ranging in salt content from 52 to 817 p.p.m., depending on water stage; however, all ponds were safe for livestock use. Nitrate, which may be toxic to livestock, occurred in negligible quantities. Since salts were lost from ponds by seepage during the summer, long-term accumulation is doubtful. The drainage to these ponds was from soils having salty depressional areas. (SWC 4-3(d1) Rev.)

2. Reclaiming of water wasted by phreatophytes. Pan evaporation measurements for the 1964 season at Winnemucca, Nevada, indicate that a clean Weather Bureau type pan set out at the beginning of the growing season, refilled weekly, and never cleaned during the season, would give seasonal pan evaporation totals sufficiently accurate to substitute in lieu of records from a properly operated and serviced Weather Bureau pan. This substantiates findings of the 1963 season.

Comparison of soil moisture changes from three profile locations within a 10- by 10-foot evapotranspiration tank during the 1964 season shows that soil profile moisture changes at the center location did not differ greatly from the average moisture change of three profile locations. Within five seasons, six of eleven plastic membrane ET tanks installed at Winnemucca, Nevada, developed leaks. Saltgrass penetration tests on strips of plastic and butyl sheeting in 1964 show saltgrass was able to penetrate all samples placed horizontally on ground surface and held in place with 5 inches of sand cover. One-sixteenth-inch butyl was the thickest sample subjected to penetration tests.

Loss of pumping prime of a multi-well system often results when a relatively low-yielding well pumps "dry." Pumping tests near Winnemucca, Nevada, verify that the difference in drawdown levels in wells of various capacities and pumped collectively can be minimized by "oversizing" the pump intake manifold to keep pipe friction losses low. (SWC 4-g1)

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AREA 5: IRRIGATION PRINCIPLES, REQUIREMENTS, PRACTICES AND FACILITIES FOR EFFICIENT USE OF WATER ON FARMS

Problem: Competition now faced by irrigated agriculture from municipal and industrial users of water for the limited supplies available is forcing the adoption of improved methods of water application and use. While rigid adherence to historical methods of allocating water has not fostered efficiency, there are other reasons. These include a lack of knowledge concerning the most efficient irrigation methods and the cost of adapting currently available procedures. Often water is cheaper than the labor required for more efficient use of water. Irrigation, historically responsible for the existence of agriculture in the arid West, has become an economic necessity in the production of high-value crops in the humid areas where annual or seasonal droughts jeopardize both the quality and quantity of crops produced.

Improved solutions to many of the problems associated with the irrigation practice, such as use of limited water supplies, methods for efficient water application, optimum time and amount of application in relation to crop growth stage, soil factors, and a practical method of determining when to irrigate, would do much to increase water use efficiency. Automation in water application has the potential for increasing water use efficiency while reducing the cost of application. Temperature control by sprinkler irrigation to maintain high crop quality is an area needing further research attention. The development of improved methods of computing (1) evapotranspiration, based on sound thermodynamic principles, including the advected energy component; (2) deep percolation losses; and (3) effective rainfall probabilities would advance the prediction of irrigation water requirements.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in irrigation, utilizing agricultural and hydraulic engineers, soil physicists, and soil scientists at various physiographic area research centers and field stations in the United States. Three PL-480 studies on irrigation are underway in Israel. The scientific and engineering effort in this area totals 24.0 professional man-years. Of this total, 13.3 are devoted to irrigation water requirements, crop response, and soil-water relations; 6.3 to water application methods--surface, sprinkler and subsurface; and 4.4 to systems design for efficient use of water and of labor in water application (automation).

PROGRAM OF STATE EXPERIMENT STATIONS

The States are conducting both basic and applied research in irrigation. At many of the States the research is conducted cooperatively with the Department.

The response and water needs of most crops are being investigated. The effects of irrigation on crop quality, quantity, uniformity of ripening, and many other factors are being determined. Basic research is also underway on the physiology of water movement into and through plants.

Research is underway to develop better design criteria for more efficient use of irrigation water. Included in this research are studies to determine optimum gradients of furrows and borders, optimum lengths of run and stream sizes, more efficient sprinkler systems, and on water intake rates as they affect design. Work is also being done on methods of determining when irrigation water should be applied for most efficient use of available water.

The total research effort in irrigation at the State experiment stations is 31 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Irrigation Water Requirements, Crop Response and Soil-Water Relations

1. Water requirements, time for application, and extraction patterns. The design of effective irrigation enterprises requires knowledge of total water requirements and maximum use rates. Efficient use of water on a particular field requires knowledge of soil-moisture depletion rates. Studies aimed at improving predictive procedures for accurately estimating these factors are continuing at several locations throughout the United States.

Evapotranspiration (E_t) from mountain meadows at altitudes of 7,340; 7,710; 8,760; and 10,100 feet near Gunnison, Colorado, indicated that net radiation (R_n), solar radiation (R_s), and evaporation (E) could not be used to accurately predict E_t. Although change in R_n or R_s was generally accompanied by changes in E or E_t, the ratios of the values changed sharply during the season due to advected energy (A) or crop harvest. Advected energy was as much as 24 percent of E_t during the weeks just before harvest. E_t, E and A during comparable periods generally decreased as altitude increased. (SWC 5-d1)

In a study of timing of preseasonal irrigation for grain sorghum at Bushland, Texas, a late fall application resulted in more available soil moisture at plant emergence (June 29) than an application during winter or spring. The earlier irrigation resulted in higher available moisture in deeper soil layers (3-6 feet). Preseasonal applied water that remained in the soil for plant use ranged from 28 percent when applied April 14 to

50 percent when applied November 20. Preseasonal evaporation losses from a nonirrigated treatment totaled 7.4 inches during an 8-month period when precipitation totaled 7.2 inches. Evaporation losses from preseasonal irrigation treatments ranged from 10.4 to 11.7 inches. (SWC 5-5(e1) Rev.)

In studies to determine minimum water requirements of lawn grasses in cooperation with the U. S. Navy at Reno, Nevada, average daily evapotranspiration for a 2-day irrigation interval was 0.29 inch per day for a loam soil and 0.26 inch per day for a sandy loam soil, and for a 4-day irrigation interval was 0.26 inch and 0.23 inch per day for the two soils. Data and observations to date show that a 4-day irrigation interval supplies sufficient moisture to maintain a lawn in a well-dressed condition during the hot part of the growing season. (SWC 5-9(g2) Rev.)

Plastic mulches are being used extensively with high-value irrigated crops to obtain earlier germination of seeds in cool climates, reduce irrigation water requirements, and to protect the marketable product from damage by contact with the soil. Use of clear plastic mulches during the warmer part of the season often results in high soil temperatures that are detrimental to the young seedlings. Studies at Twin Falls, Idaho, have shown that a water-filled plastic mulch, acting as a heat sink during the day and a source at night, resulted in 26°F. lower mean maximum soil temperatures at the 10 cm. depth. These studies indicate that the beneficial effects of a plastic mulch can be retained without detrimental high temperatures by using a water-filled plastic mulch. Minimum temperatures are higher with this mulch. The degree of temperature attenuation can be modified by the depth of water maintained between the plastic layers. (SWC 5-f1)

At Norfolk, Virginia, control of evaporation from the soil by sealing plots with black plastic, reduced the water requirement such that a crop of sweet corn was produced solely with the water stored in the soil profile at seeding. Increased soil temperature with the plastic permitted more rapid germination and early growth rate compared to bare plots. During a long, dry period, corn on the bare plot receiving no irrigation was severely wilted; whereas, on plots sealed with plastic, the corn remained quite turgid even though soil moisture was as low as or lower than that in the bare plots. Relative turgidity of leaves from the sealed plastic plots was 90 percent compared to 78 percent for the bare nonirrigated, and 85 percent for the bare irrigated plots. Corn yields from the sealed plastic plots were 89 percent of the bare irrigated plots, whereas yields from the bare nonirrigated plots were only 64 percent. (SWC 5-a1)

Predicted daily moisture use rates at Thorsby, Alabama, were relatively close to measured rates when the predictions were based on current pan evaporation, current net radiation, and average use rates from previous years. The deviations of predicted from measured rates in inch per day were 0 to 0.068 for pan evaporation, 0.001 to 0.110 for net radiation, and 0.001 to 0.137 for previously determined use rates. The larger deviations

were caused primarily from the inability to determine when excess moisture in the soil profile from large rainstorms drained to the field capacity level. The soil moisture measurements indicated this time was related to the amount of rainfall, and sometimes was in excess of 48 hours. Even so, the possibility of using daily climatic data for predicting irrigation requirements was indicated by these results. (SWC 5-b1)

The daily rate of moisture use by corn for silage at Thorsby, Alabama, ranged from about 0.10 inch per day when the plants were young to more than 0.30 inch per day as the plants approached maturity. The daily use rate was increased by irrigation, reduced with a ground cover of black plastic, and affected only slightly by plant population of 15,000 and 30,000 plants per acre as well as row spacing of 20 and 40 inches. (SWC 5-b1)

Records of soil moisture extraction under Coastal bermudagrass at Watkinsville, Georgia, showed that during the relatively wet summer of 1964, most of the water used was from the upper 24 inches of the soil horizon. Clipping frequencies of 2, 4, and 6 weeks had no measurable influence on the rate and amount of moisture use for the season. (SWC 5-b1)

In a PL-480 study in Israel, consumptive use coefficients for grapes, groundnuts, apples, plums, and cotton compared favorably with those published for similar climatic areas in Arizona and California. Mean daily hours of direct sunshine and mean daily temperatures correlated significantly with evapotranspiration determined from soil moisture samples. (A10-SWC-11)

2. Crop response to water, fertilizer, and other management practices for efficient water use. A grain sorghum irrigation-row spacing study at Bushland, Texas, indicated that sorghum planted in double rows (two 12-inch rows on 40-inch beds) increased yields up to 820 pounds per acre, compared to single 40-inch rows, at higher yield levels of 5,000 to 7,000 pounds per acre under moderate to adequate irrigation. Row spacing did not affect yields appreciably at lower yield levels of 3,000 to 4,000 pounds per acre obtained under very limited irrigation. Total water use by the double rows was about the same as that by single rows; therefore, the increased yields from double rows at the higher yield levels resulted in more efficient use of water. (SWC 5-5(e1) Rev.)

Applying water in every other furrow (60 vs. 30 inches) to irrigate sugar beets on Pullman silty clay loam soil at Bushland, Texas, and less frequently in every furrow decreased seasonal water use; however, yields were reduced proportionately. Results indicate that total water requirements of sugar beets in the Southern High Plains are almost double the requirements for grain sorghum and winter wheat. (SWC 5-5(e1) Rev.)

Eight irrigation regimes ranging from three to nine applications were tested on safflower at the U. S. Water Conservation Laboratory, Tempe, Arizona. The consumptive use, estimated from soil moisture depletion data, varied from 23 inches of water for the three-application treatment to 53 inches for the nine-application treatment. Yields varied from 2,000 pounds

per acre for the three irrigation applications to 4,500 pounds per acre for the nine irrigation applications. Optimum production was achieved where seven applications yielded 4,400 pounds per acre with a consumptive use of 42 inches. Oil content and weight of weeds increased as the number of irrigations increased. (SWC 5-9(g2) Rev.)

Yields of Coastal bermudagrass were increased with irrigation on Cecil sandy loam at Watkinsville, Georgia, with nitrogen applications of 200, 600, and 1,000 pounds per acre (all with 2:1 N-K ratio), and with 2-, 4-, and 6-week clipping frequencies. Increasing the time between clipping increased the yield with or without irrigation, as did increasing the rate of nitrogen application. The ton-per-acre increases in dry forage per inch of irrigation water applied at the 200-, 600-, and 1,000-pounds per acre N rates, respectively, were 0.102, 0.233, and 0.237 for the 2-week clip; 0.162, 0.208, and 0.208 for the 4-week clip; and 0.161, 0.184, and 0.193 for the 6-week clip.

Per acre dry-weight yields of corn silage at Thorsby, Alabama, were increased 4,100 pounds with irrigation, 1,200 pounds with 30,000 vs. 15,000 plants per acre, 1,800 pounds with black plastic mulch vs. no mulch, 500 pounds with 20-inch rows vs. 40-inch rows, and 300 pounds with 300 vs. 150 pounds N per acre. Green weights were affected in a similar way with these variables. (SWC 5-b1)

Tobacco investigations at Blacksburg, Virginia, with Kentucky 16 and Kentucky 16 Mammoth, using three plant spacings and two soil moisture levels, showed lower leaf areas for the high soil moisture regime (75 and 100 percent of available soil water) than for the low soil moisture regime (25-100 percent of available soil water). Total leaf yields for both varieties were greater for the low soil moisture regime with 18" x 42" x 40" spacings, but the reverse was true for the 20" x 20" spacing. The highest Leaf Area Index of 8.8 was obtained on the conventional 18" x 42" spacing with the Mammoth variety and not on the 20" x 20" spacing as was expected. Dry matter yield and value per hundredweight were both favored by the low soil moisture treatment. The data suggest that soil aeration may be a limiting factor in obtaining greater LAI values. (SWC 5-a1)

3. Water intake, transmission, storage and deep percolation. The available-water-holding capacity of a soil--field capacity minus the moisture content at the wilting point--is used extensively in the design and projected operation of an irrigation system. The available-water-holding capacity is generally assumed to be independent of the evapotranspiration rate. In several recent publications, authors have theorized that the effective water-holding capacity would be greater with an actively transpiring crop than under bare soil conditions, or low evapotranspiration rates. This increase in effective water-holding capacity has now been confirmed in a field study at Prosser, Washington. Alfalfa plots were irrigated lightly throughout the 1963 season when signs of severe moisture stress occurred. This pre-treatment reduced the moisture content in the 30- to 60- inch depth to the wilting percentage at the end of the season. In July 1964 when regrowth

following the first harvest was about 10 inches high, sufficient irrigation water (6.45 inches) was applied to bring the 0- to 36-inch depth to field capacity on plots clipped and covered to prevent evapotranspiration and on nonclipped plots. If the 0- to 39-inch depth is considered, the amount of water that drained from this zone in 10 days was 0.58 inch on the clipped and covered plots as compared to 0.19 inch on the alfalfa plots, or the effective water-holding capacity was increased about 0.4 inch on the alfalfa plot (the average evapotranspiration rate was 0.3 inch per day). After 24 days, a total of 1.1 inches of water drained from this zone on the clipped and covered plot whereas on the alfalfa plot, water was being used from depths below this zone. These studies verify that the effective water-holding capacity of the soil is influenced by the evapotranspiration rate. (SWC 5-f1)

The importance of horizontal and vertical movement of soil water in meeting crop requirements was demonstrated on a Collington sandy loam soil at New Brunswick, New Jersey. Yields of beans grown in soil columns in which various boundary restrictions were imposed were 50 percent less where both horizontal and vertical soil water movement was restricted than where either one or both types of water movement were unrestricted. Tensiometer readings indicated that both lateral and vertical movement of water into the columns was responsible for the higher yields. (SWC 5-a1)

B. Water Application Methods

1. Surface irrigation techniques, hydraulics and water absorption. The low gradient bench irrigation system installed on Pierre clay at Newell, South Dakota, has provided an effective means of conserving limited irrigation water supplies by increasing water application efficiency. High application efficiency to irrigated pastures requires a stream size ranging from 0.04 to 0.08 c.f.s. per foot width of border or from 2 to 3 c.f.s. in the pipeline distribution system. A storage reservoir designed and constructed to facilitate use of larger stream sizes within the range indicated provided a means of concentrating suboptimal water deliveries from the Belle Fourche Project distribution system. Water stored can be fed directly into the farm pipeline distribution system by gravity for maximum operation, flexibility and efficient water application. Rainfall that normally would run off graded irrigation systems is also conserved by retention in the nearly level basins to supplement limited irrigation supplies. (SWC 5-d1)

The accurate measurement of water flowing in irrigation furrows without altering the natural flow conditions has in the past plagued research workers. At Logan, Utah, two devices which had suitable characteristics for field use were developed and tested. One, a vane-type impulse meter was adversely affected by channel irregularities, depth of flow and wind movement in the field. A second device consisting of a motor-driven flow meter

performed well in the field with an accuracy of measurement of 2.5 percent. When tested on furrows having a slope of 0.6 percent, the disturbance of the normal flow level in the furrow was not more than 1/8-inch, and then for only a few seconds. It will be used to study the infiltration phenomena under an advancing furrow stream. (SWC 5-8(g1) Rev.)

2. Sprinkler irrigation techniques, water distribution and intake. The magnitude of water loss by evaporation and spray drift with a sprinkler irrigation system influences the design and efficiency of the system. Estimates of the quantity of water loss by evaporation and spray drift must be made under diverse climatic conditions when designing sprinkler systems. A theoretical analysis of the evaporation loss from water droplets indicated that without the addition of heat, the evaporation of only about 1 percent of the water in a drop would lower the water temperature to the dew point temperature of air under summer climatic conditions in Idaho. Therefore, the amount of radiant and sensible heat available to vaporize water must be the major factor controlling evaporation loss instead of the water vapor pressure in the air. Spray drift would be influenced by wind speed. Analysis of field data collected during sprinkler studies in the Boise, Idaho, area supports this theory. Higher correlations were obtained between spray losses and wind speed, solar radiation, and air temperature than with the vapor pressure difference between the irrigation water at its normal temperature and the vapor pressure in the air. (SWC 5-f2)

Using a portable sprinkler evaluation device designed and constructed at Reno, Nevada, a large variation in sprinkler design intake rates was found for various crops on a single soil type. Examples of measured average intake rates by soil types are: (1) Scism silt loam, southwest Idaho, 0.18 inch per hour in the bottom of a potato furrow, 0.30 inch per hour for alfalfa, and 0.56 inch per hour on wheat stubble; (2) Portneuf silt loam, southeastern Idaho, 0.14 inch per hour in potato furrows, 0.30 inch per hour for pasture, and 0.37 inch per hour for alfalfa; and (3) Keko sandy loam, south-central Idaho, 0.46 inch per hour in the bottom of potato furrows, 0.69 inch per hour for alfalfa, and 0.79 inch per hour for pasture. The lowest rates were measured in the furrow on row crops where the soil had been worked many times with farm tractors and other equipment in seedbed preparation, planting, cultivating and spraying crops. The data cited clearly indicate that the cropping pattern and crop management procedures as well as the soil type must be considered when selecting a design water application rate for a farm. (SWC 5-8(g1) Rev. and SWC 5-f2)

3. Subsurface irrigation techniques and equipment. Flow rate in porous tile used for subirrigation of Tifway bermudagrass in sandy soil at Fort Lauderdale, Florida, changed with time from an initial flow rate in excess of 0.25 inch per day to about 0.02 inch per day. This was inadequate for the moisture demands of the grass. Laboratory tests with distilled water, rainwater, and mineralized well water showed the tile was clogged with

bacterial growth and mineral deposits. Chemical treatments to prevent these deposits were partially successful. Tests are being continued. (SWC 5-b1)

Preliminary study of several devices for subsurface application of water to citrus at Riverside, California, indicates considerably less water was applied to young trees by the subsurface method than by use of spitter-type sprinklers. Adequacy of equipment to handle salt problems and to supply water needed for mature trees is undetermined. (SWC 5-8(g1) Rev.)

C. Systems Design for Efficient Use of Water and of Labor in Water Application

1. Irrigation efficiency. New irrigation projects are continually being constructed and old projects are being revised and improved. New water distribution systems and operation practices are needed to raise the farm irrigation efficiencies above the 45 to 55 percent range in water-short areas and where construction and operation costs are high. The factors controlling or limiting farm irrigation efficiencies must be delineated to improve distribution systems and operating criteria. A joint USBR-ARS study in southern Idaho indicated that in 1964 farmers generally used 24-hour irrigation sets that resulted in excessive amounts of water applied at each irrigation. Also irrigations were not spaced at progressively longer time intervals after August 15 when potential evapotranspiration was decreasing. These two factors significantly contributed to low irrigation efficiencies in 1964. (SWC 5-f2)

In an irrigation efficiency study in the Milford, Utah, area involving 150 wells, the pumping plant efficiencies ranged from 24 to 70 percent. With 1964 power rates, the power cost per day to pump 2 cubic feet per second against a total head of 90 feet would be $6.98 for a 60-percent plant efficiency and $13.32 for a 30-percent plant efficiency. The irrigation season power bill for an 80-acre farm would be approximately $500 higher for a 30-percent efficiency than for a 60-percent efficiency. (SWC 5-8(g1) Rev.)

Return flow systems are being used extensively in areas where water is scarce or where deep well pumping costs are high. Return flow systems pump irrigation runoff water from a field or fields back to the contributing area, or to another field. A preliminary survey of 66 return flow systems in southern Idaho indicated very little design data were used or are available for use, and the initial costs of the systems were high ($24 to $60 per acre irrigated by the system). Annual power costs ranged from $1 to $3 per acre. As operated, silt removal and disposal costs may be as high as power costs. No flow measurement devices were used and none of the systems had automatic controls. The results of this survey are being used in the first stage of the development of design and operating criteria for efficient return flow systems. (SWC 5-f2)

Graded furrow irrigation studies at Bushland, Texas, on Pullman silty clay loam soil indicate that long furrows (1/2 mile) can be irrigated with an application efficiency of about 90 percent. The soil has a rather high initial water intake capacity; however, a dense layer in the second foot causes the intake rate to drop rapidly to the very low level of 0.05 to 0.10 inch per hour and limits water intake and storage largely to the top foot of soil. Distribution of water in the soil profile was not affected appreciably by length of run. This intake characteristic of a high initial quantity and a very low terminal rate along with the absence of significant deep percolation loss results in efficient furrow irrigation with the long irrigation runs common to the Southern High Plains. (SWC 5-5(e1) Rev.)

2. Automation. The major cause for inefficient use of irrigation water, particularly on surface-irrigated systems, is the high labor cost coupled with inexpensive water. Farmers are reluctant to use additional labor just to conserve water. Rather, the farmer often adjusts water application time to labor patterns dictated by general farm operations. Automation of water applications on surface-irrigated systems offers one way to conserve water use on many farms--for the farmer who automates a well-designed irrigation system to save labor will automatically save water.

Two types of pneumatic valves, developed at Fort Collins, Colorado, are capable of being remotely operated for application of irrigation water to graded border strips, to level or nearly level basins and to furrows supplied either from underground pipeline or open-ditch distribution systems.

The essential components of the automated system consist of: (1) a pneumatic rubber valve or closure, (2) a three-way solenoid control valve that "inlets" or "exhausts" air from the butyl, nylon-reinforced pneumatic valves or closures, (3) a source of air pressure to inflate the closure, and (4) a centrally located, remote control system with timing device to actuate the three-way solenoid control valve by means of a signal carried either by wire or transmitted by radio.

The pneumatic butyl rubber valve for pipeline distribution systems is essentially an inflatable O-ring mounted between the "alfalfa" valve seat and valve lid. It is held in position by a centrally located metal sleeve capable of sliding up and down the threaded screw supporting the valve lid. In an open position, the pneumatic valve is forced against the bottom of the valve lid and appears to "ride" on top of the water flowing through the alfalfa valve. In an inflated or closed position, the pneumatic valve forms an annular seal against the valve seat and valve lid. About 5 to 10 pounds per square inch of air pressure in the pneumatic valve are usually sufficient for most pipeline irrigation systems.

The lay-flat pneumatic valve for farm ditch systems is a flat, rectangular tube that inflates to form a closure within the underground portion of the turnout pipe. It is secured to the turnout pipe at the upstream end and when deflated or in an open position conforms to the

curvature of the pipe wall. As the valve inflates with air, it expands upward and outward until closure is complete against the walls of the turnout pipe and flow of water ceases. About 2 to 3 pounds per square inch of air pressure are required for complete closure of this valve.

The automated irrigation system described has been operated by radio command at distances up to 4 miles. After presetting a timer to trigger the radio transmitter at hourly intervals at the Seedskadee Development Farm, Fontenelle, Wyoming, 36 acres were irrigated during a 9-hour period on an experimental basis with lay-flat valves in ditch turnouts without touching the water or system. A stream size of 10 cubic feet per second was used.

These automation devices are best suited to systems requiring changes in irrigation "sets" at short intervals of 6 hours or less. It is in such systems that labor costs are highest. (SWC 5-d1)

At Twin Falls, Idaho, development of mechanized, automatic and semi-automatic water control structures involving two components--the timing of remote control device to initiate the action, and the mechanical structure to hold and/or release the water is in progress. Stainless steel tubing, used in various sizes and lengths to control the flow of air or water in a timing mechanism, does not plug as easily by the accumulation of small bubbles and lint as do needle valves because a larger cross-sectional flow area is maintained. Field tests of butyl check dams equipped with mechanical timers, have shown these to be practical for checking and automatically releasing irrigation water in an unlined ditch after a predetermined period of time. (SWC 5-f2)

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AREA 6: DRAINAGE PRINCIPLES, REQUIREMENTS, PRACTICES, AND FACILITIES FOR PROTECTION OF CROPS AND SOILS

Problem. Excess water is the dominant hazard to 245,563,000 acres or 17 percent of the land in the United States.[1/] For the cropland area, excess water is the dominant problem on 59,906,000 acres or 14 percent. Water management systems have been applied to some 140,000,000 acres of potentially wet lands in the United States. More than 90,000,000 acres are in organized districts and the remainder are individual farm enterprises. More than 60 percent of the acreage in organized districts is in seven Corn Belt States. The U. S. Census Report for 1960 shows an expenditure during the last ten years for new drainage work of nearly $186,000,000 and a cost of maintenance, operation, and repair of more than $231,000,000.

There are numerous water management problems on these lands. High water tables during the spring restrict root development, which lowers the plants' drought resistance during the dry periods that generally follow. Water ponded in microtopographic depressions delays plantings beyond optimum dates, and makes the use of modern high-speed farming equipment uneconomical. Hillside seep areas function similarly to reduce farming efficiency. Conventional methods of subsurface drainage are costly. Drainage design is generally based on empirically determined drainage coefficients instead of precisely developed drainage or aeration requirements of specific crops.

The economic success and feasibility of many irrigation projects depend on adequate subsurface drainage to prevent salting out and abandonment of the projects. On more than 50 percent of the irrigated acreage in the 17 Western States, or more than 15,000,000 acres, drainage is a necessary complement for successful operation.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of land drainage utilizing agricultural and hydraulic engineers, soil physicists, and plant physiologists at various physiographic area research centers and field stations throughout the United States. The scientific and engineering effort in this area totals 20.0 professional man-years. Of this total, 1.6 are devoted to surface and open ditch drainage; 5.6 to subsurface conduit drainage--new materials, hydraulics, installation

1/ U. S. Department of Agriculture, Agriculture Information Bulletin 262, 1962.

equipment and techniques; and chemical and biological clogging of tile; 2.7 to drainage for salinity control; and 10.1 to design of optimum systems--drainage requirements of plants; soil properties, flow in porous media, analog and computer programs for systems design; and systems performance--sloping and flatlands.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are conducting drainage research related to humid areas as well as on irrigated lands.

Research is being conducted on land shaping for improved surface drainage; effective depth and spacing of subsurface drains; special problems on slowly permeable soils; and the effectiveness of pumping from underground aquifers for drainage. Studies are also being conducted on the feasibility of plastic subsurface drains and the use of fiberglass as an envelope around drain tile.

Design and maintenance requirements of surface drainage systems are being studied. Research is also being conducted on the causes of ditch bank failures in surface drainage systems.

More rational design criteria for drainage systems on irrigated lands are being developed. Basic research is underway to determine the dynamics of water flow through various soils and into drains. Applicability of proposed drainage formulas is being tested by means of models and computer techniques. Part of this research effort is supplied by the cooperation of four stations and the USDA in Western Regional Research Project W-51.

In addition to the work reported above, research is underway on general problems of drainage design and water table control. Much of the total drainage research by the States is in cooperation with the Department.

The total research effort in drainage research at the State experiment stations is 19 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Surface and Open Ditch Drainage

1. Landforming, cut-fill effects and remedial measures. Exposure of subsoils as a result of landforming of sloping land near Chatham, Virginia, has had little or no detrimental effect on tobacco yields over a three-year period. Cut areas produce somewhat lower yields at first than fill areas, but these are no longer significantly less than those from transition areas. Areas where topsoil was stockpiled and replaced did not produce better tobacco than areas where land was formed without regard to final location of topsoil. The former treatment cost $280 per acre, whereas the latter

cost only $90 per acre. This field study has shown that once nutritional requirements are met, maintenance of adequate profile soil moisture and prevention of surface drying are critical for food production on these fine-textured subsoils. (SWC 6-a1)

2. Row and drain specifications and systems development. Research and field experience have shown that surface disposal of excess rainfall is practical on land in sugarcane, cotton, and other crops in the Mississippi Delta. Design data, however, on row lengths and grades for orderly disposal of the excess surface water are generally not available. On studies in progress at Baton Rouge, Louisiana, with row lengths of 500, 700, 900, and 1,100 feet, and grades of 0.10, 0.15, 0.20, and 0.25 feet per 100 feet, the yields of corn silage in 1964 were not affected by these lengths and grades. Similar results were obtained in 1962, whereas in 1963 the yields increased as row grade became greater. These 3-year results suggest an interaction effect between climatic conditions and row grade and length on yields. (SWC 6-b2)

B. Subsurface Conduit Drainage

1. New materials--laboratory and field tests of performance. A large part of the high cost of subsurface conduit drainage has been the material handling and installation cost. Studies have been underway at several locations to lower these costs by use of plastic mole drain liners. The potential for savings is high.

In Ohio, results show that flexible thin-walled plastic mole drain liners (15 mil. wall thickness x 3 inches in diameter) deformed and decreased in diameter considerably under the existing soil loads during the fourth year after installation. For the first time in four years, the peak drainage outflow rates were significantly reduced as the result of the reduction of drain size. However, even though peak rates were reduced, the drain still functioned satisfactorily to provide adequate water table control. The peak flow rates were of less than one day's duration. The Ohio studies also showed that the zippered-plastic mole drain liners should be installed at a depth of 30 inches or greater in these clay soils to prevent damage by deep plowing when the subsoil moisture content is high. (SWC 6-c1)

At Logan, Utah, it has been demonstrated that the zippered plastic mole drain liners are apparently satisfactory for irrigated field use if no unusual loading conditions develop. The thin-walled plastic has a very small bending moment and any concentrated point load either hydrostatic or mechanical will cause buckling and collapse of the lining. To insure maximum strength, the plastic liner should be installed as nearly circular as possible. (SWC 6-g2)

At Columbus, Ohio, conduit-load-supporting theories have been postulated and mathematical equations developed for use in designing mole drain liners.

It was shown that the load-supporting properties of the plastic drain liners can be expressed in terms of conduit flexibility which will make it possible to develop design criteria with a minimum of laboratory testing. (SWC 6-c1)

In laboratory tests at Logan, Utah, it was found that flexibility may increase load-bearing capacity of drain conduits if lateral soil pressure can be developed. In comparative tests made in dry sand where lateral support was ideal, the flexible conduits showed relatively high load-bearing strength. (SWC 6-g2)

Electric analog studies at Brawley, California, to compare flow characteristics and relative flow rates into filters that only partially covered the conduit with those into filters that completely cover the conduit, showed greater flow occurs when the filter completely covers the conduit.

In other drainage research at Brawley, California, a compartmental tank was used to test the relative merits of gravel, glass fiber mat, and glass fiber sheet filters. Flow rates were greatest from the gravel filter and least from the glass fiber sheet. The hydraulic conductivity of the glass fiber sheet was greater than the glass fiber mat; however, flow rates were greater from the mat. This indicates that the hydraulic conductivity of a material is not a sufficient criterion for selection of the filter without a thickness factor.

Differences in the hydraulic properties of filter materials will cause differences in outflow from soil-filter systems if the soil infiltration and conductivity rates do not restrict water movement. As soil infiltration decreases, the differences in outflow due to the filter differences will decrease. Thus it is difficult to compare filter materials in the field since for many soils the "bottleneck" is the soil itself and not the filter material. (SWC 6-g2)

2. Installation equipment and techniques. It has been shown in Ohio that the tool-bar-mounted mole plow for installing zippered plastic linings can be operated satisfactorily on side slopes up to 20 percent and with rather large sandstone rock below the surface. Such conditions of excessive slope and rocks in the soil make the use of conventional tile trenching machines impractical. When rocks are present, a preliminary pass of the mole machine is made to remove the rock. The liner is installed during the second pass of the machine. (SWC 6-c1)

A trenching machine and installation procedures have been developed at Weslaco, Texas, for automatically laying 4-inch semirigid plastic drainage pipe in a trench 10 inches wide. This was a cooperative venture with a drainage contractor and a manufacturer of plastic pipe. Installation procedures, perfected in the laboratory, were incorporated into the machine which forms a semicircular cradle in the undisturbed soil material of the

trench bottom. The cradle conforms to the shape of the pipe and provides lateral support for the semirigid material. The continuous plastic drain tube installed in a narrow trench permits use of a less-powerful and lighter trenching machine, reduces tree damage in orchards because of the smaller machine, requires a smaller crew to install the drains, and eliminates misalignment problems experienced with short sections of pipe. (SWC 6-12(e3))

3. Chemical and biological clogging of tile. At Brawley, California, studies were initiated to determine the cause and extent of the manganese and iron-oxide deposition in tile lines. The field study phase for problem orientation has indicated the problem occurs in many parts of the valley and is not restricted to a particular type or size of tile. Particular attention is being given to the chemical characteristics of the ground water, including redox potential. (SWC 6-g2)

C. Drainage for Salinity Control

At Riverside, California, data collected during steady water flow processes in pressure-membrane apparatus indicate that there is a significant increase in impedence in the vicinity of both the inflow and the outflow membranes. Whether this increase in impedence is distributed through the first few millimeters of soil or is dominantly expressed at the soil-membrane interface is not yet known. The minimum hydraulic gradient that occurred midway between the inflow and outflow ends of the soil sample was about one-fourth the over-all gradient that would be found by assuming a linear hydraulic head distribution across the whole system. For the Pachappa soil that was used in this experiment, evidence of non-Darcian flow behavior appeared at average suctions as low as 154 cm. of water.

The one-step outflow method was used to determine the temperature dependence of the soil-water diffusivity of a silt loam soil. Tests were conducted at 5^{o}, 24^{o}, and 35^{o}C. The results agreed with results that were previously obtained by the constant flux method in that at a particular water content, the change in diffusivity with temperature was about twice the change that would be expected because of the attendant changes in the viscosity of water. At all water contents for this soil, the measured diffusivity at 35^{o}C. was about four times that measured at 5^{o}C. Such pronounced temperature effects will influence both the rate of evaporation of water from the soil surface, the availability of water to plants, and salinization of the soil. (SWC 6-gF1)

D. Design of Optimum Systems

1. Drainage requirements of plants. Excess soil moisture creates an unfavorable environment for plant growth by restricting the aeration of plant roots. The primary purpose of a drainage system is to remove excess water from the soil so that aeration is restored before plant roots are affected adversely.

Studies at Raleigh, North Carolina, show close relationships between the aeration status in the soil and plant responses with different depths to the water table. Yields of snapbeans were optimum at a water-table depth of 30 inches in sheltered lysimeters when water was applied to the soil surface similarly as by rainfall. Severe yield reductions occurred with water tables at 16 and 12 inches. Oxygen partial pressure measurements showed poor aeration in the entire soil profile with the higher water tables for several days after water was applied to the soil surface. Aeration was good to a depth of 9 inches or more where the water table was 18 or more inches deep. Where the water table was static and no surface water was applied, the best yields were obtained with 12-inch depth to water because the upper soil layer that contained most of the roots did not become too dry as it did with the deeper water tables. Use of a newly developed membrane-covered electrode showed low rates of oxygen diffusion and a low oxygen content 6 to 12 inches above the water table, indicating little aeration in the capillary fringe.

Oxygen consumption by intact roots of young corn plants was about 0.17 millimole of O_2 per gram of dry roots per hour. When anaerobiosis was developed by replacing oxygen with nitrogen in a growth chamber, cell division and elongation of roots stopped within 5 hours. Most of the root tips died if exposed to these conditions for 24 hours, and recovery of those living was very slow when oxygen was restored to the roots. (SWC 6-b1)

Investigations at Norfolk, Virginia, showed that sweet corn and tomato yields increased with increasing depth to water table from 6 inches to 32 inches below the soil surface, but snapbeans were relatively unaffected. Sweet corn and beans yielded better at high water table levels on fine-textured soil (Othello silty clay loam) than on a coarse-textured soil (Rumford loamy fine sand). The evapotranspiration rate of corn increased with increasing depth to water table. Water use efficiency of corn and tomatoes increased greatly with increasing depth to water table but no significant differences were observed for beans. Total water use and water use efficiency were also affected by soil type. Analyses of tomato leaves showed that the Ca, Mg, Fe and N contents generally increased with increasing depth to water table. Laboratory incubation studies of the three soils used showed that soil nitrates increased with increasing length of incubation and decreasing soil moisture content, whereas the reverse was generally true for ammonia. It is apparent that the drainage requirement of plants, as it relates to yield, water utilization and composition, varies with species and soil type. (SWC 6-a1)

2. Soil properties, water tables, flow in porous media, analog and computer programs for systems design. At Fleming, Georgia, analyses of chemical and physical properties of soils related to drainage in the Atlantic Coast Flatwoods area continue to show little or no susceptibility of these soils to increased acidity from aeration due to drainage. The total available water capacity in the top 36 inches of the 18 soil series studied ranged from 0.70 inch in Ona sand to 7.92 inches in the Bladen series. Preliminary results from 16 hydraulic conductivity measurements in 6 soil series showed

rate of water movement ranged from 0.006 inch per hour in the fine sandy loam of the B_1 horizon on the Goldsboro series to 1.824 inches per hour in the loamy fine sand of the A_2 horizon of the Fairhope series. The limited data suggest that hydraulic conductivity is related to sand particle size, soil texture, quantity of roots, and perhaps other factors. (SWC 6-b2)

Soil freezing has a marked influence on soil drainage and moisture storage characteristics of Fargo-Bearden soils in the Minnesota Red River Valley. Beginning in December, the soil freezes from the surface downward at the rate of about 1-1/2 to 2 feet per month and reaches a maximum depth of from 4 to 6 feet by about the middle of March. The maximum depth of freezing is from 1 to 1-1/2 feet greater where there is little or no protective surface cover such as for fallow soil or land in soybean stubble, as compared to an area having a cover of bromegrass or alfalfa. The soil thaws out mostly from the surface downward, beginning about the middle of March, and the last frost leaves the soil sometime between the middle of April and the middle of May. Early snowmelt and spring rains, coming when the soil is still frozen, result in excessive runoff which increases the drainage problem and reduces the amount of water available for crop growth. Abrupt rises in the water table coincide with the disappearance of the frost from the soil profile. (SWC 6-c1)

The problem of soil heterogeneity makes it difficult to obtain satisfactory measurements of soil hydraulic conductivity. At Columbus, Ohio, hydraulic conductivity values were determined on a soil monolith and compared with measurements obtained using the dry auger hole method. The dry auger hole values were only 1/10 to 1/20 those measured for the monolith. Evaluating water-transmission properties of soils continues to be a major problem in drainage design. (SWC 6-c1)

At Logan, Utah, in research to determine soil sampling requirements for hydraulic conductivity, it was found that a definite mathematical relation exists between the variance and the means, or average, of hydraulic conductivity data. The successive addition of data from successive samplings in the same soil is a valid procedure for obtaining an average value. The mean hydraulic conductivity is less variable than individual samples and a 50 percent probability level can therefore be used with confidence. (SWC 6-g1)

Analytical procedures and the digital computer were used at Raleigh, North Carolina, to develop a theoretical approach to the frequency distribution of water table height as a function of soil, system parameters and climatological data. These analyses and experience suggest this approach is feasible for drainage system design, but that additional work is needed to account for surface water disposal and deep-seepage losses. (SWC 6-b2)

At Urbana, Illinois, studies have been designed to develop more precise methods for determining the physical parameters needed for use in equations required for solution of waterflow problems that occur in drainage and

irrigation. During the past year a computer program has been written that computes the water content and diffusivity from gamma scintillation data of a horizontal infiltration. This has speeded analysis of the diffusivity data. A technique for determining diffusivity by using field cores and the horizontal infiltration technique has been tested on a few samples. It is valid for determining diffusivity in the middle ranges of water content. Also, a special flow case involving hysteresis has been solved and laboratory tested. (SWC 6-c1 and 11-c3)

3. Systems performance--flat and sloping lands. In a drainage study on a sloping, seepy Cabot loam soil at East Franklin, Vermont, diversion terraces with and without tile showed no difference in volume of water removed per acre for either 200- or 400-foot terrace spacings. Combined surface runoff and tile effluent for 100-foot tile spacings amounted to 4-1/2 inches over a 4-month period as compared to 4 inches for 200-foot tile spacings. Only 2-1/2 inches were removed from areas with only the terraces. Soil moisture measurements showed no significant differences for the two terrace spacings, but tiling with 100-foot spacings resulted in lower soil moisture contents in the surface foot than were found for the 200-foot spacing or where no tile was present. Diversion spacing had no effect on the yield or botanical composition of the forage stand. Plots having either tile spacing yielded slightly better than plots having no tile. Forage composition of plots having 100-foot tile spacings averaged 76 percent alfalfa for the third cutting as compared with 61 percent for the 200-foot spacing and 49 percent for no tile. These early observations indicate that tiling is very effective in drainage of these sloping fragipan soils. (SWC 6-a1)

At Castalia, Ohio, there continues to be a significant difference in corn yields due to drainage. However, the method of drainage is of little significance. Corn yields were equally good where either surface or subsurface drainage was provided, or where the two were combined. The corn yield data indicate that the effects of inadequate drainage on crop yield for this soil can be mitigated by the addition of nitrogen, but yields were substantially greater by use of both drainage and nitrogen.

As compared to an undrained plot during the spring of 1964 (an unusually wet season), it was possible to plant corn one week earlier on plots with surface drainage only and two weeks earlier where tile drainage or a combination of tile plus surface drainage was provided. (SWC 6-c1)

The annual water use by grass sod at Fort Lauderdale, Florida, has averaged 43 inches per year with a water table depth of 24 inches. With the average annual rainfall of 62 inches, an excess of 19 inches of water must be disposed of through surface or subsurface drainage. Monthly excesses ranged from 4.5 inches in June to -0.5 inch in February. (SWC 6-b1)

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AREA 7: SALINE, SODIC, AND RELATED SOILS PROBLEMS, AND QUALITY OF IRRIGATION WATERS AND THEIR RELATION TO PLANT GROWTH PROCESSES

Problem. Salinity is a continuing and major problem in irrigated agriculture. In the arid West injurious concentrations of salts in the soil have impaired the use of 25 percent of the irrigated land. Fifty percent of this area is endangered. Salinity or brackish water problems in the eastern seaboard area have increased with the rapid expansion of supplemental irrigation in this area where tidal streams and creeks are a conveniently available source. Soil salinity problems exist in many dryland farming areas in semiarid regions.

Salts move upward in the soil with water to supply evapotranspiration requirements and are left behind as the moisture passes to the atmosphere. This results in injurious accumulations in the root zone unless excess water as rain or overirrigation is periodically passed downward to leach the salts to the ground water or to a tile drainage system for removal in the tile effluent. These salts generally come from the irrigation water, although some soils naturally contain excessive quantities of harmful salts. The nature of the salts, soil, and climatic conditions and leaching water quality create complicated problems, many of which have not been solved. The use of salt-tolerant plants offers releif, but these palnts must be identified and developed. Disposal of salts without degrading water quality for the downstream user is a critical problem.

Research must continue to develop fundamental theories and principles concerning the relations of saline irrigation waters and salt-affected soils to the plant growth processes, and techniques for use of these principles in diagnosis and improvement of saline and sodic soils and waters in specific field situations.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research in the area of saline and sodic soils and quality of irrigation water for the growth and production of agricultural crops and ornamental plants. Scientists involved in this research include physicists, chemists, soil scientists, plant physiologists, agronomists, and agricultural engineers. The center for basic research in this area is the U. S. Salinity Laboratory, Riverside, California. Brackish water studies for the Atlantic Coast flatwood resource areas are centered at Norfolk, Virginia, with supporting work in New Jersey and Georgia. Salinity problems of the Rio Grande Plain and Lower Valley areas are under study at Weslaco, Texas, of the Red River Valley at Mandan and Grand Forks, North Dakota, and of the Snake River Valley at Twin Falls, Idaho. In addition, 3 PL480 studies are underway in Israel.

The scientific and engineering effort in this area totals 23 professional man-years per year, nearly two-thirds of which is at the U. S. Salinity Laboratory. Of the total professional man-years, 7.0 are devoted to mechanisms of reactions, soil properties and diagnosis and the soil-water-plant system; 7.2 to physiological basis for plant tolerance, and adaptation and response of plants; 2.9 to water composition, ground water and salt balance; 3.0 to water, soil, and crop management systems for saline and sodic soils; and 2.9 to leaching processes.

PROGRAM OF STATE EXPERIMENT STATIONS

Most of the Western States and a few States in other regions are conducting fundamental and applied research on saline and sodic soils and quality of irrigation water in relation to plant growth. Generally these investigations are closely cooperative with those of the Department. Expansion of the research programs in this program area is anticipated as soil salinity and water quality problems become more serious.

Reclamation investigations are underway in several States. In Colorado, the effects of deep tillage and management of soils having hardpans or layered textured discontinuities have been determined. The chemical characteristics of slick spot soils and chemical and physical means of increasing permeability is being examined by Idaho and Illinois scientists.

In Arizona, research at the Safford Branch Station is largely devoted to salinity problems. The influence of bed shape and planting and irrigation practices on the germination, stand and yield of row crops on saline and saline-alkali soils is under study. A recently initiated project is concerned with a comparison of sprinkler vs. furrow irrigation with saline water in crop production.

Eight stations are participating in Western regional project W-82, Soils, Pesticides and the Quality of Water, which is concerned with the interactions between pesticides, soils and waters that may influence the degree of pollution of ground and surface waters. Emphasis is being placed on the mechanisms of movement of pesticides from the soil to the water supply.

Studies also are being made of the tolerance of citrus under field conditions where variable salinity conditions are built up in soil from use of irrigation waters of different quality, laboratory procedures for the diagnosis of salt-affected soils, the salt tolerance of various varieties of crops, leaching requirement for keeping salts out of the root zone, the lithium content of surface and well waters and its effect on crops, and the effect of various ratios and amounts of cations and anions on plant growth.

The total State research effort on soil salinity and water quality problems area is 6 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Mechanisms of Reactions, Soil Properties, Diagnosis and the Soil-Water-Plant Systems

1. Mechanisms of reactions between dissolved, and absorbed constituents of salt-affected soils. Both chemical and physical requirements must be satisfied before sodic soils can be reclaimed. The chemical requirements can be determined from cation exchange equilibrium relationships and chemical analyses of the soil.

At Riverside, California, field-plot and laboratory studies using soil columns approximately 60 cm. long have shown that the depth of water, D_w, of a particular total salt concentration and cation composition that is needed per unit depth of soil profile, D_s, to effect a certain amount of reclamation can be described as follows:

$$\frac{D_w}{D_s} = \frac{\rho \, CEC \, \Delta \, (ESF)}{F \, \Delta \, (Ca+Mg)}$$

ρ is the bulk density in g/cm.^{3}; CEC is the cation-exchange-capacity in me/g.; F is an efficiency factor that accounts for leakage through large pores, poor contact between soil solution and cation exchange sites, etc.; Δ (ESF) is the reduction in the exchangeable-sodium-fraction (ESF = 0.01 x exchangeable-sodium-percentage); and Δ (Ca+Mg) is the reduction in the divalent cation concentration in me/ml. in the leaching solution as it flows through the soil. For homogeneous profiles, the product of ρ and CEC is constant. The efficiency factor, F, can usually be taken as unity unless the soil is badly fractured. Both Δ (ESF and Δ (Ca+Mg) can be calculated from the chemical composition of the leaching solution and the prevailing exchangeable-sodium-percentage (ESP) of the soil. D_w/D_s is thus expressed as centimeters of water per centimeter of soil profile depth. (SWC 7-gF1)

2. Structure, organic matter and microbial relations in salt-affected soils. Studies at Riverside, California, have demonstrated the utility of quantitative mineral determinations on soil clays as a means of explaining soil behavior. Soil clays from two large alluvial basins have been quantitatively characterized to determine the magnitude of mineralogical variations occurring in these soils, and to determine whether such variations are coupled with textural variations. The possibility has also been investigated of using abbreviated techniques for determining the approximate clay-mineral composition of additional soils from these areas, after the initial detailed analysis of a small number of samples has been completed.

Soils from the Imperial Valley of California showed only minor variations in clay-mineral composition, in spite of pronounced textured variations. The soils thus lend themselves naturally to studies in which attempts are made to correlate soil physical and chemical properties with soil texture.

Soils from the Punjab area of West Pakistan, on the other hand, exhibited wide variation in clay-mineral composition, with no significant correlation of mineral composition with soil texture. Up to 65 percent quartz plus feldspars occurred in the $<2\mu$ fraction of these soils. Both surface area and cation-exchange-capacity were highly correlated with the amount of $<2\mu$ quartz and feldspars present, thus providing a convenient means for correcting mechanical analysis data for the presence of nonreactive material. (SWC 7-gF2)

3. Methods for diagnosis and study of salinity in soils and water. At Riverside, California, encouraging tests have been made of a sensor for continuous in-place measurement of the electrical conductivity of the soil solution in the film phase. The sensing element uses the operating principle described by Kemper and consists of metallic electrodes fixed in a small fine-grained ceramic block that is buried in soil. Recent improvements in design have reduced the response time and external field effects. The time required to complete 63 percent of the change in the equilibrium readings when a unit is transferred from one bulk solution to another is one or two hours. When tested in soil in the pressure membrane apparatus, about two-thirds of the units gave essentially no change of reading when the matric suction was changed from 0 to 5 bars. If stability of calibration and convenient temperature compensation can be attained, these sensors should be usable for following salinity status in farmers' fields. In addition, these units should expedite the refinement and use of soil-water management principles, such as the "leaching requirement". (SWC 7-gF3)

At Weslaco, Texas, in a study of aerial photography for remote-sensing measurements of soil salinity, it was possible to associate a specific color tone with each of five levels of salinity. Nonirrigated cotton was used as an indicator plant to relate the salinity in the 0- to 5-foot profile at reference locations to that at prediction sites where the salinity was unknown. Aerial photographs were taken using Ektachrome infrared aero film. This development should make possible the mapping of soil salinity in nonirrigated areas on the basis of film interpretation from photo transparencies with a minimum of soil measurements. Research is now being directed toward extending the technique to irrigated areas. (SWC 7-18(e2))

4. The soil-water-plant systems under saline conditions. At Riverside, California, theory for the dependence of thermocouple psychrometer output electromotive force (e.m.f.) on temperature, pressure, psychrometer geometry, as well as water potential in the sample has been developed from basic laws of heat and vapor transport between the sample in the psychrometer and the wet junction. Good agreement was found between psychrometer e.m.f. predicted by this theory and that found experimentally under various conditions. These analyses also provided the basis for several changes in psychrometer design which should improve their performance for the study of the soil-water-plant system. (SWC 7-gF4)

B. Physiological Basis for Plant Tolerance, Adaptation and Response of Plants

1. Physiological basis for plant tolerance to saline soil and water. Studies on the suppression of plant growth by salinity at Riverside, California, indicated that salinity reduces the rate of synthesis of DNA, RNA, and protein as well as the rate of cell enlargement and of cell division. In bean leaves, the duration of DNA synthesis, essential for cell division, is rigidly controlled by a regulatory mechanism or biological clock which appears to be outside the leaf itself. Salinity failed to delay this clock even though it markedly reduced the rate of DNA synthesis. The net result was less DNA synthesized, fewer cells produced, and hence, smaller leaves on the salt-affected plants. The duration of cell enlargement in bean leaves is evidently controlled by a separate regulatory system, although cell enlargement and cell division were coordinated as long as the latter occurred. Chloride salinity prolonged cell enlargement, especially the elongation of palisade cells, and the accompanying synthesis of RNA and protein. Palisade cells in the affected leaves grew to nearly twice their normal length. This phenomenon probably accounts for the greater thickness and succulence of leaves often found under saline conditions. Other studies with bean and cotton plants have shown that high humidity, in some cases, virtually abolished the suppressive effect of salinity on growth. (SWC 7-gF6)

Although not required for normal plant growth, sodium, a major constituent of saline soil solutions, is absorbed by roots of plants grown on saline soils. Some plants retain most of the sodium in the root, whereas others readily translocate sodium to the shoot. In some instances, injury occurs as a result of excessive concentrations of sodium in the leaves. Experiments are being conducted at Riverside, California, to determine the mechanism that regulates absorption and translocation of sodium in plants. Indicator plant species being used for these studies are beans (a nontranslocator) and cotton (a translocator).

The metabolic inhibitor, 2,4-dinitrophenol (DNP) had very little effect on the total amount of sodium absorbed by bean plants but reduced the amount of sodium retained in the roots and increased the amount translocated to the shoot. In cotton, total absorption, retention in the roots, and translocation to the shoot were all reduced by DNP. The percent reduction was very nearly equal for all three processes. Similar results were obtained with other inhibitors such as sodium azide, iodoacetate, chloramphenicol, and low temperature.

In cotton, sodium translocation increased as the rate of transpiration was increased. However, in beans, such a relationship between translocation and transpiration occurred only in plants either treated with DNP or without roots. The rate of change in the amount of sodium translocated to the shoot per unit change in transpiration was the same for both bean and cotton plants without roots. The sodium distribution within the shoot was very different for beans and cotton. In beans, the concentration decreased from stems to petioles to leaf blades, whereas in cotton, the concentration was lowest in

leaf blades but more nearly equal in the stems and petioles. (SWC 7-gF7)

2. Tolerance of plants to salinity. Further work on the salt tolerance of sugarcane at Riverside, California, has centered on the detailed analyses of plant samples from greenhouse and field-plot studies with NCo 293 and 310 varieties, and the initiation of comparable experiments with the Hawaiian variety H50-7209.

In greenhouse cultures, all three varieties were similarly affected by low salinity, suffering a 15-percent reduction in cane yield at an EC_e of about 3.5 mmhos./cm. At higher salinities, consistent varietal differences in salt tolerance appeared so that at 7.6 mmhos./cm., reductions in yield were 42 percent for NCo 293, 56 percent for NCo 310, and 68 percent for H50-7209. Of primary concern is the significant reduction in yield at low salinity, a reduction which the highly competitive sugar industry can hardly tolerate. Sugar content was higher in NCo 310 than in NCo 293 under saline conditions. Low salinity reduced the sugar content of NCo 310 but not of NCo 293. Higher salinities significantly decreased sugar content of both varieties, primarily by retarding growth and by increasing the proportion of young cane in the millable stalk. Salinity decreased the reducing sugar content and increased the mineral content of expressed cane juices.

A small greenhouse drum-culture study was conducted at Riverside, California, on the salt tolerance of the perennial legume, Sphaerophysa salsula, introduced from Australia. Yields of forage were reduced 10 percent at 4 mmhos./cm., 25 percent at 5.5 mmhos./cm., and 50 percent at 9.2 mmhos./cm., EC_e . It is thus only somewhat more salt-tolerant than alfalfa. The hope that this species might represent a highly salt-tolerant legume and, therefore, a more useful range plant was not realized. Salt accumulation by Sphaerophysa salsula is quite low. Chloride and especially sodium are maintained at low levels, even under the more saline conditions. (SWC 7-gF5)

At Riverside, California, observations during a second growing season on 13 shrub species in sand cultures and plots have indicated the following ranking with respect to tolerance: Moderately to highly tolerant: Dracaena, Natal plum, rosemary, bougainvillea, Dodonea, and Euonymus; moderately tolerant: Silverberry, hibiscus, star jasmine, Japanese boxwood, and Heavenly bamboo; sensitive: Algerian ivy and Burford holly. Observations are being continued to assess the effects of salinity on sensitivity to frost and to correlate salt injury with salt accumulation in the leaves.

At Riverside, California, Cardinal and Thompson seedless grape scions grafted on five different rootstocks were subjected to three levels of chloride in a series of sand cultures. During the first season of differential treatment, consistent rootstock responses were observed. As in a previous study, Cardinal roots developed the highest chloride concentrations in the leaves of both scions, and Thompson seedless roots resulted in somewhat less than half these levels of leaf chloride. Dog Ridge resulted in somewhat lower chloride accumulation than even Thompson seedless, and

1613-3 and Salt Creek produced the lowest leaf-chloride levels. Average leaf chloride accumulation on the high-chloride treatment (50 meq/l.) ranged from 0.05 percent for Dog Ridge to 1.2 percent for Cardinal. There was thus a 25-fold range in leaf chloride with different rootstocks. Different scions on any given rootstock generally exhibited similar levels of chloride accumulation, indicating that the rootstock was the dominant factor in regulating chloride levels in the leaves. This experiment will be continued for at least two years to determine the persistence of these patterns of differential chloride accumulation. Pruned canes are also being analyzed for accumulated salts. This information can be of great value in prescribing suitable grape rootstocks for salt-affected areas. (SWC 7-gF8)

At Weslaco, Texas, Coastal bermudagrass and rhodesgrass produced good yields (8.4 and 9.4 tons respectively) under dryland conditions, and yields were reduced only slightly under conditions of moderate salinity. When grown on plots having an average EC_e of 4.7 and 8.4 mmhos./cm., the yields were reduced approximately 1 ton per acre dry weight. The percentages of Na^+, K^+, Ca^{++}, and Mg^{++} in the grasses grown on saline soil varied little from those grown on adjacent nonsaline soil. The data indicate that Coastal bermudagrass and rhodesgrass could be grown on the dryland areas of south Texas where intermittent saline areas occur. (SWC 7-e1)

3. Salt tolerance of plants under humid conditions. Intermittent droughts, particularly on sandy soils with low water holding capacity, make irrigation an important farm practice in the intensive production of vegetables and other high-value crops along the Atlantic Seaboard. Often the only available water is the brackish water in the tidal streams of the area or wells where salt water has encroached into the underground supply.

Results of 3-year studies at New Brunswick, New Jersey, and Fleming, Georgia, on factors affecting the use of brackish water for supplemental irrigation revealed that bean yields increased from 0 to 83 percent depending upon the amount and salinity of the water applied. Salinity ranged from 0 to 6 mmhos./cm. in 5 steps. Results in 1964 confirmed previous observations that the salt tolerance of beans is much greater when saline water is applied at or after floral initiation, thereby emphasizing the importance of growth stage at time of salinization in determining salt tolerance. No significant residual salinity was observed in the spring at any of the locations. No significant effect of saline irrigation was observed on the fall crop of kale, collards, and turnips. (SWC 7-a1 and SWC 7-b1)

Studies at Norfolk, Virginia, reported last year indicated that evapotranspiration losses from tomatoes in a greenhouse study decreased not only with increasing salinity, but also with P fertilization. Similar results were secured with beans this past year. The depressing effect of P fertilization on evapotranspiration was observed primarily on the salinized treatments. (SWC 7-a1)

C. Water Composition, Ground Water and Salt Balance Studies

Precipitation of calcium carbonate from irrigation water applied to soil increases the sodium hazard of the water. At Riverside, California, an index of the tendency of calcium carbonate to precipitate from irrigation waters has been developed. The index, designated pH_c, was initially developed for a closed system in which no loss of CO_2 occurs. Because soil cannot be regarded as a completely closed system with respect to gas exchange, the validity of the index over the range of partial pressures of CO_2, P_{CO_2}, ordinarily encountered in soil (.00033 - .01 atm.) was determined. At P_{CO_2} = .00033 atm. the coefficient of correlation between pH_c and the amount of precipitation that occurred when irrigation waters were equilibrated with added calcium carbonate was -.97. A similar good relation was obtained at P_{CO_2} = .01 atm. The extent of precipitation, however, was decreased uniformly by amounts nearly equal to the increase in the solubility of $Ca(HCO_3)_2$ at P_{CO_2} = .01 atm. as compared to the solubility of P_{CO_2} = .00033 atm. Thus, for both closed systems and those having a constant P_{CO_2} in the soil range, the pH_c value of a water is an index of the tendency of $CaCO_3$ to precipitate from the water.

In a field lysimeter experiment underway to determine the amounts of $CaCO_3$ that precipitate in soil irrigated at various leaching percentages with waters having various pH_c values, irrigations during the summer of 1964, were such that the soil in the lower portion of the lysimeter remained nearly saturated. Under these conditions, the drainage water from all lysimeters had Ca and HCO_3 concentrations of 20 and 30 meq./liter, respectively. As the solubility of $Ca(HCO_3)_2$ even at P_{CO_2} = 1 is only about 16-17 meq./liter, it is evident that markedly supersaturated solutions of $Ca(HCO_3)_2$ can develop in waterlogged soil. That the saturation is associated with waterlogging was proven by the much lower concentrations of Ca and HCO_3 (10-15 meq./liter) obtained when the soil throughout the lysimeters was allowed to become fairly dry before irrigation. This appears to be a previously unreported finding and the causes of the supersaturation are under investigation. (SWC 7-gF10)

D. Water, Soil and Crop Management Systems for Saline and Sodic Soils

At Grand Forks, North Dakota, experiments at two field locations differing in salinity and depth to the shallow, saline water table showed that bare fallow substantially reduced salinity of the upper part of the soil profile, the reduction being greater on the site with the lower water table and salinity. Use of a straw mulch during winter ahead of the fallow further reduced salinity of the surface soil. These results confirm those reported last year showing that salinity decreased under fallow, remained about the same when barley was grown for 3 years, and increased in a bromegrass meadow cut for hay. In another experiment, salinity remained just as high after a 3-year test period on 5-acre plots that were leveled as on plots that were left with their undulating microrelief. Leveling was done to remove the saline ridges with their reduced opportunity for

infiltration. A tile drain also installed 3 years ago was not effective because the water table remained below the tile line except for a very short period in 1964. (SWC 7-d1)

Yield and moisture use of cotton grown in lysiemters at Weslaco, Texas, were significantly greater as a result of a considerable reduction of salinity in the soil profile by leaching. Water tables were maintained at depths of 3, 6, and 9 feet. Mean lint cotton yields for the 3-, 6-, and 9-foot water table treatments were 1,820; 1,617, and 1,592 pounds per acre, respectively for the leached soils, compared to 704; 989, and 950 pounds per acre, respectively for the non-leached soils of the previous year. The increase in moisture use in the leached soils was approximately proportional to the increase in yield. These data show that, even though cotton is salt tolerant, yields can be appreciably increased by leaching and drainage. (SWC 7-e1)

Various surface cover materials and conditions have been effective in reducing evaporation and increasing downward movement of water and salinity under natural rainfall conditions near Weslaco, Texas. The materials and conditions are sand-gravel mulch, cotton gin trash mulch, Coastal bermudagrass, and bare fallow. The EC_e was reduced by 95, 93, 89, and 57 percent of the initial level in the surface 2 feet of the sand-gravel, gin trash, bare fallow, and Coastal bermudagrass plots, respectively. In the 0- to 7-foot profile depth, the EC_e was reduced by 62, 62, 34, and 3 percent of the initial EC_e concentration in the same plots. Gypsum had no significant effect on increasing reclamation in any of the treatments. (SWC 7-e1)

Farmers are rapidly accepting deep plowing--30 to 36 inches--as a management practice for soil improvement and for reclaiming unproductive areas of saline-sodic "slick spot" soils of the Northwest. Such soils occupy large areas of irrigated land in southwestern Idaho and southeastern Oregon. Approximately 5,000 acres of the Chilcott-Sebree soil complex in southwestern Idaho have been deep plowed. Reclamation is accomplished primarily because the intake rate and penetration of irrigation water increases with deep plowing. Studies at Ontario, Oregon, have shown that deep plowing Malheur (slick spot) soil in southeastern Oregon to a depth of about 33 inches increased the depth of water penetration from about 6 inches on the check areas after 2-3 days of continuous irrigation to about 33 inches in less than 24 hours. Deep plowing the entire field increased the depth of water penetration from about 17 inches to 33 inches on the associated Nyssa (nonsaline) soil, essentially doubling the root zone and effective water holding capacity of the entire field. (SWC 7-f1)

E. Leaching Processes

Because rice culture is commonly used in the reclamation of sodic soils, a study was undertaken at Riverside, California, to separate actions of the rice crop itself upon reclamation from effects arising from the passage of large volumes of water through the soil during growth of the crop. Most soils were reclaimed considerably faster under rice culture. For coarse-textured soils, this increased reclamation rate was largely a reflection of increased soil hydraulic conductivity, with the amount of sodium removed from a given soil being a function only of the depth of water passing through the soil. For a soil of fine texture, successive increments of water passing through the cropped soil eventually became more effective in removing sodium than corresponding increments of water passing through the non-cropped soils. The point at which this increased effectiveness of cropping became significant corresponded to the point at which the hydraulic conductivity of the cropped soil began to increase significantly above that of the noncropped soil. Laboratory studies have linked the increase in hydraulic conductivity to the removal of entrapped air from soil pores, with rice culture apparently accelerating this process. While the growth of rice indirectly facilitated the removal of exchangeable sodium by enhancing the soil hydraulic conductivity or by increasing the percentage of the cross-sectional area serviced by conducting pores, the rice appeared to have no significant direct chemical effect upon the reclamation process. (SWC 7-gF11)

Investigations designed to evaluate the effectiveness of winter rainfall in leaching salt accumulations in humid area soils, resulting from fall applications of different dilutions of synthetic sea water, showed no residual salinity on a Rumford loamy fine sand at Currituck, North Carolina. Winter rains leached a major portion of applied salt from a Woodstown fine sandy loam at Norfolk, Virginia, and a Sassafras fine sandy loam at Painter, Virginia, but evidence of salt treatments were apparent in the 36-inch profile throughout the year. Nevertheless, the amount of residual salinity in the spring would not be detrimental to crop growth. During early summer, with no additional sea water applied, soil salinity increased somewhat in the surface 2 feet as a result of evapotranspiration losses and fertilization. The electrical conductivity of the soil saturation extract rarely exceeded 1.5 mmhos./cm. in the surface foot during spring and summer. (SWC 7-a1)

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AREA 8: WATER AND WIND EROSION CONTROL PRINCIPLES, PRACTICES, SYSTEMS AND PREDICTION METHODS

Problem. Water and/or wind erosion control continues to be a problem in all areas having cropping systems that require plowing, tilling, and planting. In both irrigated and dryland farming areas, wind erosion is a problem. Sand blasting has caused serious damage to young plants in the sandy eastern seaboard vegetable-producing areas. Careless application of irrigation water has resulted in serious erosion. Erosion is the major source of stream pollution in humid and semi-arid areas. The Soil Conservation Service's Soil and Water Conservation Research Needs reports continue to stress the urgency of erosion research.

Erosion control practices require constant development to meet the needs of a constantly improving farm technology and the expanding use of multirow farm equipment. The wide variations possible under factors of soil, climate, crops, and management create highly complex relationships and make it imperative to determine basic principles governing the movement and loss of soil and water. Improved control measures and prediction equations developed from these principles will provide a scientific basis for application of control practices, identification of potential sediment sources, preparation of land use recommendations and selection of critical areas for retirement to permanent vegetation.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of water and wind erosion utilizing soil physicists, soil scientists, analytical statisticians, and agricultural engineers at various physiographic areas and field stations throughout the United States. The scientific and engineering effort in this area totals 28 professional man-years per year with 8.6 devoted to basic principles and mechanics of water and wind erosion; 13.6 to interrelations of climate, soil, topography, cover, and management to wind and water erosion; 1.7 to equations for predicting soil and water losses; and 4.1 to practices, structures, and systems for modification of soil movement by wind and water.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in fundamental and applied studies of the basic principles and mechanics of water and wind erosion. These studies seek better understanding of the magnitude of forces involved in wind movement across soil surfaces and in the impact of falling raindrops.

The dissipation of this energy in terms of soil compaction, detachment of particles and movement of soil is being investigated. Studies are underway on effects of soil physical and chemical properties, plant cover, tillage, surface roughness and other related factors on the nature and extent of water and wind erosion.

Interrelationships of factors influencing the occurrence and extent of erosion are being studied. Erosion losses vary with differences in climate, soil properties, topography, tillage and management. Field and laboratory studies are in progress seeking to evaluate the effects of individual factors and determine interrelationships between various combinations. Research is directed toward evaluation of tillage, surface mulching and crop rotation practices which influence the physical and moisture properties of the soil. Terracing, strip cropping and contouring are evaluated individually and in combination for effectiveness in erosion control and suitability under modern farming procedures.

The total research effort on water and wind erosion problems at the State experiment stations is 17 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Basic Principles and Mechanics of Water and Wind Erosion

1. Mechanics of wind and water erosion. Laboratory studies at Orono, Maine, have shown that similar erosion occurred from Caribou loam when storms of comparable erosion potential (EI) were applied. Splash losses from 5.1-mm. drops falling at near terminal velocity were more than twice those from 3.2-mm. drops. Distance of splash was greater with the larger drops. (SWC 8-a1)

Raindrop splash-pattern studies at Morris, Minnesota, showed that the largest splash occurs for a surface water depth of about 2 mm. Changes in depth affect the splash shape in various ways, including a change in splash direction from about vertical at depths of greater than 2 mm. to about 45° outward at very shallow depths. At a constant drop-diameter to water-depth ratio of 4.2, the shapes of the splash craters were nearly identical for drops varying from 3- to $5\frac{1}{2}$-mm. in diameter. For inclined impact surfaces, the upslope and downslope splash angles decreased as the slope increased. At a slope of 45°, the downslope splash angle decreased with increasing surface roughness and with decreasing drop size.

Studies of raindrop size distributions and fall angles at Urbana, Illinois, confirmed that the previously published drop size distributions used to evaluate the rainfall factor of the universal erosion equation are satisfactory for Corn Belt conditions. The studies also showed that most major rainstorms occur with wind velocities which cause raindrops to fall at angles of 30° or more from vertical. This information is important in relating the impact kinetic energy of rainfall to the resulting erosion.

Laboratory studies at Brookings, South Dakota, showed some of the effects of wind on the trajectory of vertically falling waterdrops such as produced by field plot rainfall simulators. The impact velocities of drops larger than 3 mm. were not appreciably affected by falls of up to 12 feet in winds of up to 20 feet per second, but the velocity of 2.2-mm. drops increased up to 7 percent. Waterdrops 5.5 mm. in diameter, falling through a 20 f.p.s. wind, drifted about 11 inches during 8 feet of fall and about 25 inches during 12 feet of fall; 2.2-mm. drops drifted almost twice as far for the same conditions. The impact angles for the larger drops were 13° at 8 feet and 18° at 12 feet and for the smaller drops were 23° and 28°, respectively. No evidence of drop breakup was found for the conditions tested. Mathematical expressions relating drift to drop diameter, fall height in wind, and wind velocity were developed. This study showed that increasing the height of the rainulator nozzles within the range studied would not significantly improve the rainulator as a research tool.

Studies of the basic mechanics of the soil erosion process at Lafayette, Indiana, showed the variables such as slope steepness, slope length, and particle size have critical limits below which no appreciable erosion occurs. The addition of critical-value terms to the mathematical erosion relationships containing these variables yielded more descriptive expressions. The effect of particle roughness was also investigated, and erosion generally increased as the roughness increased from smooth sand to angular sand to crushed glass cullet. Evidence was also found that erodibility of a given size group decreased as the range of particle sizes increased.

The erosion rate from the normal 0.60-meter plot width was compared with rates from two 0.30-meter widths and from four 0.15-meter widths. The erosion per unit of width generally decreased as the plot width decreased. This decrease was greater for the smaller particles and for the steeper slopes, conditions for which runoff normally has a greater tendency to concentrate. (SWC 8-c1)

Tests were made in an open-channel flume at Watkinsville, Georgia, to determine the critical tractive force of various soils. The critical tractive force, Tc, is the shear stress on the soil at the time soil particles begin to move in flowing water. It is expressed by the formula $Tc = \gamma DS$, where γ is the specific weight of water in lbs./ft.^{3}, D is depth of flow in feet, and S is slope in ft./ft. The Tc values for 6 soils tested ranged from 0.00488 for Appling sandy clay loam to 0.00575 for Cecil sandy loam. The relation of depth of flow to discharge could be described by the equation, $Q = AD^B$, where Q is rate of discharge, D is depth of flow, and A and B are constants that varied for each soil. The constants A ranged from 8.28 to 11.92, and constants B from 1.74 to 1.92. Outflow from the porous bed beneath the test flume indicated infiltration rates of these soils during individual tests varied from a high of 1.39 in./hr. for Iredell sandy clay loam to a low of 0.18 in./hr. for Herndon silt loam. Slight increases in bulk density of each soil during each run indicated some reorientation of particles due to the movement of water through the soil body. The relation of these values to the physical and chemical properties of these soils is under study. (SWC 8-b2)

Work at the new erosion research laboratory for the Northwest at Pullman, Washington, has been limited to checking the equipment and exploratory work involving the plot car, freezing and thawing equipment, and the rainmaking apparatus. The laboratory has been designed for use of field size plots for the freezing and thawing studies under simulated rainfall and with slope steepnesses up to 45 percent. (SWC 8-f2)

2. Soil erodibility. The field measurements and associated laboratory determinations for 12 additional soil types and textures made during the year in Indiana and Minnesota supported the effective use of soil-physical properties for mathematical computation of soil erodibility. With similar measurements in the past 4 years on other soils, these data have helped to identify the soil properties most influential in determining infiltration characteristics, soil stability, and transportability of soil by rainfall and runoff. A generally applicable soil-erodibility equation based on readily measured soil properties, which now appears near, will enhance the utility of the universal soil erosion equation as a guide to land-management decisions. (SWC 8-c2)

Results of erodibility studies at Watkinsville, Georgia, in 1964 on soils in the Southern Coastal Plains and the Carolina Slate Belt areas confirmed previous findings that textural class is a far better indicator of erodibility than is the soil series. The ascending order of erodibility by textural class, with the appropriate K value, is clay (.13); loamy fine sand (.14); loamy coarse sand (.17); loamy sand (.19); loamy sand-sandy loam (.20); sandy clay loam (.23); sandy loam-sandy clay loam (.24); coarse sandy loam (.27); clay loam-clay (.42); gravelly sandy clay loam (.42); silt loam (.42); loam (.43). Erodibility of clay soil was low because of the high degree of aggregation. With the exception of this soil texture, the amount and size of the sand fraction exerted a dominant influence on the erodibility of the soil. (SWC 8-b1)

In a laboratory study at Ames, Iowa, erosion increased with increasing antecedent moisture for coarse-textured soils such as the Ida silt and Kenyon loam, but the reverse was true on fine-textured soils such as the Marshall and Grundy silty clay loams and Luton silty clay. Apparently, in the case of the fine-textured soils, the aggregates were more stable if initially wet, and this resulted in less surface sealing. (SWC 8-c2)

The first three years of a field plot study at Madison, South Dakota, showed the Poinsett soils of that climatic region to be highly erodible. The erodibility-factor value for these soils was 0.54 in comparison to 0.33 for the Marshall and 0.38 for the Fayette soils of Iowa and Wisconsin. Field plot studies at Morris, Minnesota, both under natural and simulated rain, showed that the Barnes loam also ranks high among Corn Belt soils in its susceptibility to erosion by rainfall. Indicated 90-percent confidence limits on the value of the erodibility factor (K) are 0.38 and 0.47. (SWC 8-c2)

3. Erosion tolerance and renewal. A basis for improved estimation of erosion tolerances for specific soils has been developed at Manhattan, Kansas, by reviewing erosion rates from small control plots with close-growing vegetation; stream discharge from large watersheds, rock weathering rates; and surface deposition rates. Soil property renewal and net change functions were considered in interpreting the data. Conclusions were that present erosion tolerance standards, based largely on judgment, are conservative for soils with large reserves of depth but are clearly excessive for shallow soils unless these soils receive exceptional soil renewal practices.

At Manhattan, Kansas, fundamental properties of a soil renewal function have been analyzed and stated in a manner that satisfied basic conservation philosophy and the erosion tolerance equation. A complex hierarchy of second- and higher-order variables is necessary to precisely delineate the renewal rate of a soil property measured over time and space. Six of the second-order variables that influence those properties most essential to the protection of improvement of the soil are: climate, organisms, relief, underlying rock, surface deposition, and present soil character. Relations of soil renewal to soil formation and soil productivity and the importance of human activities in determining both erosion and renewal have also been explained. (SWC 8-10(e2) Rev.)

Analysis of samples obtained from a 13-station cooperative dust trapping network now operating in the United States east of the Rocky Mountains and headquartered at Manhattan, Kansas, indicates quantities of dust influx to be large enough to influence soil genesis and soil renewal. Amounts have ranged from 10 to 3,600 pounds per acre monthly. Amorphous silica (opal) identified as phytoliths from native grasses has been prominent in many silt separates and may be useful as a tracer material. Kaolinite and Ox-amorphous particles have been prominent in clay fractions, whereas montmorillonite has been scarce or absent. Primary minerals other than quartz have been less abundant than reported previously for loess or dust-storm deposits. The "base rate of influx" concept for dust at each location, comparable to the "base flow" of streams, seems to have some validity, pending longer periods of checking. (SWC 8-e1)

A study in New York to evaluate the ability of eroded land to recover its productivity under good soil management showed that soil, once severely eroded, can be restored to adequate production but the process is slow by conventional management practices. In 1942, two sets of plots, severely eroded (ex-fallow) and noneroded (ex-meadow), were planted to corn with good management practices. During the first ten years, corn yields on the eroded plots were approximately 50 percent of those from the noneroded. Since 1952, yield differences have decreased and during the past two years before termination in 1964, there were no significant differences. (SWC 8-a1)

B. Interrelations of Climate, Soil, Topography, Cover and Management

1. Water runoff and erosion. Runoff from a Honeoye soil in New York with three tillage methods--conventional, zero tillage and wheel track planting--tended to increase as the steepness of slope increased but to decrease as length of slope increased. Runoff losses from the zero tillage treatments were almost double those from the conventional and wheel track treatments. (SWC 8-a1)

At Holly Springs, Mississippi, on 1/4-acre plots with controlled row grades of 0.33 percent, runoff increased with an increase in land slope, being 10.4 inches on $2\frac{1}{2}$ percent, 12.3 inches on $4\frac{1}{4}$ percent and 17 inches on 10 percent land slope. Erosion on these plots also increased as land slope increased, but at a greater rate than for runoff, being 7.3, 9.2, and 23.5 tons per acre, respectively, for the three land slopes. The ratio of erosion loss from the $2\frac{1}{2}$ percent slope to that for the 10 percent slope, however, equalled 3.2 in comparison to a ratio of 5.2 developed as a long-time trend for a similar land slope increase with up and downhill cultivation. This confirms earlier trends for these controlled row-grade plots. (SWC 8-b1)

At Hastings, Nebraska, erosion increased as slopes increased from 3 to 7 to 12 percent on a Holdrege silt loam. Three simulated storms were applied (2.5 inches per hour for 1.4 hours; 2.5 inches per hour for 1 hour; and 5.0 inches per hour for 0.3 hour). The duration of the storms had little effect on the rate of erosion once peak runoff was reached. However, rates of erosion were greatly increased by increased storm intensity. The steeper the slope, the sooner runoff began during the first storm. Significant differences in intake were not measured on the three slopes with the exception of decresed intakes on plots with 12 percent slope when subjected to the 5-inch-per-hour intensity storm. (SWC 8-8(d1) Rev.)

Results on Cecil sandy loam at Watkinsville, Georgia, Tifton loamy sand at Tifton, Georgia, and Loring silt loam at Holly Springs, Mississippi, show that cropping treatment has a marked effect on water losses, as well as soil losses. Runoff from the Cecil sandy loam with 7-percent slope was 42, 11, and 10 percent of the 72.5 inches rainfall during 1964 from fallow soil, continuous corn, and corn after Coastal bermudagrass, respectively. Runoff on the Tifton loamy sand on 3 percent slope was 27, 5 and 0.2 percent of the 68.8 inches rainfall during 1964 from fallow soil, peanuts after corn and oats, and second-year bahiagrass, respectively. Similar data on the Loring silt loam showed water losses of 56, 14, and 20 percent of the 52.4 inches rainfall during 1964 from fallow soil, corn, and common bermudagrass respectively. (SWC 8-b1)

A plot study on Barnes loam at Morris, Minnesota, is instrumented to measure water loss during winter and spring thaw periods as well as from rainfall. In four years of measurement, most of the runoff from hayland resulted from melting snow and ice. Snowmelt runoff from the hay plots was between 80 and 90 percent of the water-equivalent of the total snowfall.

This indicated that only a very small portion of the moisture from snow contributes to the replenishment of soil moisture in the northern Great Plains. (SWC 8-c2)

Increased soil losses due to rock removal on a Caribou silt loam at Presque Isle, Maine, ranged from 0.3 to 47 percent over the four-year period, 1961-1964, depending upon rainfall distribution, with an average value of 26 percent. This increased soil loss was eliminated by crushing and returning rocks to the field. With the rocks removed, runoff was increased by 25 percent, whereas with the rocks crushed and returned to the field, the increased runoff was 9 percent. Over the same four-year period, soil losses were 138 percent greater, and water losses 65 percent greater, under continuous potatoes than for potatoes grown in a rotation with oats and sod. For 1964, there were no significant differences in potato yields as a result of crop rotation or rock removal. (SWC 8-a1)

Continued research at Lincoln, Nebraska, to find ways to stabilize embankments against water erosion during grass establishment has shown that 6 to 9 tons of woodchips per acre effectively reduced soil erosion and competition from broadleaf weeds on Sharpsburg silty clay loam. A greater number of seedlings emerged under treatments using asphalt and asphalt-mulch combinations, but competition from weeds prevented adequate establishment of fescue stands. (SWC 8-8(d1) Rev.)

At St. Anthony, Idaho, a 5-year study in the loessal Upper Snake River dryland area, where spring runoff from frozen soil is a serious problem, showed that either chiseling or rotary subsoiling after harvest increased the available soil moisture by about 0.7 inch, accompanied by corresponding decreased runoff. Winter wheat yields were increased 1.8 bushels by this additional moisture (26.0 for tilled vs. 24.2 for untilled). (SWC 8-f1)

Studies on the Midwest claypans at McCredie, Missouri, showed a very substantial effect of soil fertility on erosion, runoff and efficiency of water use. In 11 years, annual runoff from continuous corn averaged 3.7 inches when no fertilizer was used, 2.1 inches with starter fertilizer, and 1.3 inches with the full-fertility treatment. Erosion losses were reduced 35 percent by the use of starter fertilizer and 58 percent by the full-fertility treatment. The 1964 rainfall was 6 inches below normal and generally at low intensities, resulting in low soil and water losses on all the test plots. However, the conservation of soil moisture by reduced evaporation, the reduction in nutrient loss in runoff, and the deeper rooting of the adequately fertilized corn resulted in corn yields on the full-fertility treatment that averaged 47 bushels per acre more than corn receiving starter fertilizer only. The adequately fertilized corn was able to obtain more than an inch of additional moisture from the 24- to 36-inch soil layer. (SWC 8-c2)

Studies in Iowa and Indiana showed that the erosion hazard on extensive acreages of productive sloping land in the Corn Belt is being substantially increased by the trend toward more intensive row cropping, even though fertility is maintained at a high level. With average corn yields of 117 bushels and all residues returned to the soil, continuous corn at Castana, Iowa, averaged 32 tons of soil loss per acre in 1963 and 1964 in contrast to 16 tons from adjacent corn following 2 years of meadow. Annual water losses from the two treatments were 3.7 and 2.7 inches, respectively. Simulated rainstorms applied to corn in various cropping systems on Russell silt loam in Indiana showed that the soil became significantly more erodible with each successive year of corn, at least through the third year. Meadow periods of 2 or 3 years were more effective in reducing erosion in subsequent corn years than were shorter periods. Associated differences in soil aggregation accounted for 70 percent of the variation in infiltration and soil erosion resulting from differences in intensity of cropping. Other acceptable erosion-control techniques must be developed to offset the loss of benefits formerly derived from use of sod-based systems. (SWC 8-c2)

2. Wind erosion. Evaluations at Garden City and Colby, Kansas, of the tillage machines' role in conserving residue for wind erosion control have clearly demonstrated a need for devising minimum tillage procedures for summer-fallowing sparse winter wheat stubble in western Kansas. 1963-64 results again showed that four and five operations during a tillage season with any implement are too many to maintain residue in sufficient quantity to control wind erosion. Maximum quantities retained at wheat seeding time this year were only about 100 and 500 pounds per acre at Colby and Garden City, respectively. Recommended minimum residue requirements for most western Kansas soils are 750 pounds per acre. An investigation of use of the minimum tillage concept, initiated because of these results, showed that some minimum tillage treatments such as use of an 8-foot V-sweep only twice during the season retained 60 percent of the original 3,800 pound-per-acre residues on the surface at wheat seeding time. Some treatments permitted excessive weed growth which used up to four times more available soil moisture than was lost from clean tillage, but good fall wheat stands were obtained on all treatments. If 1965 wheat yields are not substantially reduced, this method or a modification of it would appear acceptable as a means of obtaining better wind erosion control. (SWC 8-e1)

At Hugoton, Kansas, portable wind tunnel tests on grain sorghum stubble with 42- and 21-inch row spacings showed a decrease in soil loss by wind with an increase in plant population density for both row spacings. The recommended planting rate for sorghum in the sandy soils of southwestern Kansas is from 240 to 480 square inches per plant. Soil loss at 480 square inches per plant was 178 percent as much as soil loss at 240 square inches per plant. Soil loss was less in 21-inch than in 42-inch row spacing. The orientation of the row with respect to wind direction was the most highly significant component in the study. Nearly three times more soil was removed with the wind blowing parallel as blowing perpendicular to row direction. For decreased wind erosion and maintenance of sorghum yields, it is recommended to (1) plant high plant populations within recommended

planting range, (2) plant in narrow row spacings, and (3) plant perpendicular to prevailing wind direction during the wind erosion season. (SWC 8-e1)

3. Rainfall simulators. A standard storm applied with the rainfall simulator at Watkinsville, Georgia, consisted of 4 increments of 30 minutes each at $2\frac{1}{2}$ inches per hour, with 10-minute intervals without rain between each successive increment. Each increment was equal to a rainfall erosion potential (EI value) of 25, with the entire storm equal to 100 EI. Such a storm was far more severe than most natural rainstorms. The K-factor value in the erosion equation for the soil loss from such a standard storm was related to the K-factor value from natural rainstorms by the formula:

$$K = \frac{14\ E_1 + 13\ E_2 + 3\ E_3 + 2\ E_4}{14\ EI_1 + 13\ EI_2 + 3\ EI_3 + 2\ EI_4}$$

where K = T/ac/EI

$E_1 \ldots E_4$ = measured soil loss from increment 1 . . . 4 of the storm

$EI \ldots EI_4$ = EI from increment 1 . . . 4 of the storm

The constants 14, 13, 3, and 2 represent the distribution of individual EI values adjusted to account for wet and dry antecedent soil moisture conditions at Watkinsville. (SWC 8-b1)

At Lincoln, Nebraska, the introduction of surface (overland) flow at the upper end of field runoff plots during a simulated storm has proven to be an important technique for evaluating the effectiveness of various mulch materials for control of runoff and erosion. The increased slope length provides more realistic "sorting" of mulch treatments used to control water erosion as the simulated slope lengths are more representative of field conditions. (SWC 8-8(d1) Rev.)

C. Equations for Predicting Soil and Water Losses

1. Water runoff and erosion. Plot-runoff analyses of assembled data at Lafayette, Indiana, brought out several important factor relationships that will help to predict surface runoff from cropland areas. Annual runoff from row-crop land was found to be directly related to slope steepness. The mathematical relationship indicated by the assembled data is: $\log W = 0.521 + 0.041s$, where W is inches of runoff and s is percent slope. The data indicate 90 percent confidence that, under normal rainfall distribution, the surface runoff from row-crop land increases between $7\frac{1}{2}$ and $12\frac{1}{2}$ percent for each additional percent of slope. With meadow or small-grain cover, the slope effect is substantially less. Although slope length had a very substantial effect on the soil content of runoff, its influence on surface runoff per unit of area was seldom of practical significance. There was a general indication of slight transmission losses in the growing season and

slight accretions in the dormant season.

Differences in organic-matter content of the soils accounted for about half of the total variance in runoff from conventionally prepared corn seedbeds on 21 silt loams and silty clay loams. On soils comprised of more than 75 percent sand, runoff was low even though organic-matter content was also low, but decreases in sand content below 60 percent did not significantly affect runoff. Variations in silt content between 25 and 75 percent also had little effect.

The relation of surface runoff to crop productivity was curvilinear and inverse. Where corn yields were less than 80 bushels, management for increased crop yields resulted in substantial reduction in runoff. The runoff-reducing effectiveness of farming on the contour increased significantly with improved soil and residue management.

Although early-seeded grass or rye-and-vetch winter covers between successive years of row crop were highly beneficial for erosion control, they generally reduced average dormant-season runoff by less than one-half inch. In northeastern Georgia, where October-through-March rainfall averages about 25 inches, the runoff reduction averaged 1.2 inches.

Average runoff from the cropped plots of studies in 24 states ranged from 3 percent to 38 percent of total precipitation. The range in average annual runoff extended from less than 1 inch to 15 inches. The utlimate goal of the study is a mathematical equation that will predict quantitatively the surface runoff from specific cropland areas. (SWC 8-c3)

2. Wind erosion. At Manhattan, Kansas, continuing efforts to improve and apply the wind erosion equation resulted in revision of the two important alignment charts used to evaluate the effect of field length, L, and vegetative cover, V, and preparation and submission for publication of a revised and condensed procedure for using the equation. The chart revisions made them easier to understand and use, and the condensed procedure, when published, will satisfy an urgent need for a readily accessible and permanent reference to the wind erosion equation. (SWC 8-e1)

At Manhattan, Kansas, a mathematical method was developed for analyzing wind data to: (1) assess the capacity of the wind to cause erosion; (2) determine prevailing wind erosion direction; (3) determine preponderance of wind erosion forces in the prevailing wind erosion direction; and (4) determine the variation of these factors throughout the year. The method is adaptable to the electronic computer and is a valuable tool for analyzing wind data to obtain design criteria for orienting shelterbelts and stripcrops for more efficient wind erosion control. (SWC 8-e1)

D. Practices, Structures, and Systems for Modification of Soil Movement by Wind and Water

1. Wind erosion control. Wind velocity measurements made at Creighton, Nebraska, to evaluate the effect of width reduction treatments on microclimate to the lee of wide shelterbelts provided additional evidence to verify use of the proposed momentum exchange method of evaluating field shelterbelt porosity. Results showed that rather small differences in shelterbelt porosity could be distinguished by evaluating the difference in momentum between an upwind and leeward location. The data also presented some evidence to support the theory that shelterbelts are most effective if they are slightly porous. The belt segments with the largest resistance coefficients, indicating greatest denseness, were slightly less effective in reducing leeward velocities than the more porous segments. (SWC 8-e1)

Investigations at Hardesty, Oklahoma, indicated the use of fertilizers to encourage growth of existing plant species to be the most economical method of stabilizing sand dunes. Variations of mulching that have been tried include complete coverage with hay scattered loose on the surface, complete coverage with hay treaded into the sand, hay mulch scattered in patches, complete coverage with asphalt, and asphalt applied in patches and strips. Asphalt mulches appear to be inferior to hay mulches. Hay mulch provides some protection either scattered loose or in bunches but is most effective when a complete cover is treaded into the sand. However, all of these methods appear too expensive for low value rangeland. Neither does growing of a mulch in place using sorghum almum, amber cane, broomcorn, rye, or barley appear feasible. (SWC 8-e1)

Field tests to evaluate plant materials for potential as single-row wind barriers have provided evidence that several kinds of plants have considerable potential for establishing effective single-row barriers at Colby and St. John, Kansas. Results are discouraging at Garden City, Kansas, where it has been extremely dry during the 2 years of these tests. The most promising trees, shrubs, and grasses are: lombardy poplar, Russian mulberry, pampasgrass, bamboo grass, common lilac, bush honeysuckle, and tamarisk. Average height of lombardy poplar 2 years after planting is 9 feet. Russian mulberry is shorter, averaging 6.5 feet, but has excellent girth growth and provides a very uniform barrier. The grasses range in height from 5 to 7 feet and the shrub heights range from 2 to 3 feet. Continuing evaluations of these plants and testing of additional plants during the next 5 years will provide a basis for recommendations for future shelterbelt plantings in the Plains. (SWC 8-e1)

Research at Big Spring, Texas, to evaluate effects of strips of grasses and other plant materials interplanted between cotton rows shows that it is impractical to attempt establishment of such practices under extreme drought conditions. Total precipitation for the year was 10.4 inches, the fifth lowest in the past 65 years, and for the growing season, April 1 through September 30, it was 5.3 inches below normal. Under these

conditions, the poor stand of Plains bristlegrass provided only limited protection from wind erosion but the millet was so short, sparse, and weak-stemmed that it was useless for wind erosion protection 1 month after the first frost. (SWC 8-e1)

2. Contour and terrace systems for runoff and erosion control. Replacement of conventional terraces with parallel terraces on one Piedmont field of 12.4 acres near Watkinsville, Georgia, increased the average length of row from 274 feet to 392 feet, or by 43 percent. Theoretical calculations of operating time showed that turning time during each cultivation would be 8 percent less with the parallel terraces, thereby reducing the work time from 0.51 to 0.47 hour per acre for a saving of 0.5 hour for the tractor and operator each time the field is tilled. (SWC 8-b2)

At Holly Springs, Mississippi, on a silt loam soil, soil losses were 78 percent less and water losses 12 percent less with contouring and parallel terraces than with the straight-row farming on small watersheds about 1.5 acres in area. Soil losses were 3.65 and 16.38 tons per acre, and runoff 11.98 and 13.58 inches for the terraced and unterraced watersheds, respectively. Rainfall was 52.43 inches with a total EI value of 400. (SWC 8-b1)

At Temple, Texas, the first year's data from studies to determine relationships between furrow length, slope, runoff, and soil loss; and to evaluate use of graded furrows as a means of increasing terrace spacing have yielded encouraging information regarding planting and maintenance procedures and significant information on runoff and erosion rates. Both sorghum and oats have been successfully planted on the furrowed land. An ordinary sweep cultivator with sweeps adjusted to the profile of the furrows and a disk cultivator were used for the first and second sorghum cultivation, respectively. These operations provided adequate weed control and maintained furrows with nearly double the runoff design capacity throughout the remainder of the growing season. Total runoff and the runoff rate from 600- and 900-foot rows were practically the same and were significantly less than from the 300-foot rows, thus indicating more moisture storage in longer rows. Sorghum yields were related to moisture storage and were about 18 percent greater from the 600- and 900-foot rows than from the 300-foot rows. (SWC 8-10(e2) Rev.)

At Cherokee, Oklahoma, where the movement of soil into terrace channels and the effect of the terrace channel on sediment production is studied with paired concrete and natural channel terraces and variable length interterrace plots, the three runoff and erosion-producing storms that have occurred since July 1, 1963, have produced nearly identical soil losses from the natural and concrete channels. (SWC 8-10(e2) Rev.)

3. Inundation tolerance of grasses. Tests to evaluate inundation tolerance of 16 grasses and 1 forb at Chickasha, Oklahoma, showed that several had sufficient tolerance to withstand normal expected duration and depth of

flooding that may occur in the detention pool of floodwater-retarding reservoirs during the spring. The ability of a particular grass to survive was affected by interactions of depth, stage of growth, duration of flooding, and temperature of water. Inundation up to 20 days had little effect in early spring but flooding during late spring and midsummer caused more damage, with severity increasing with increased depth and duration. Grasses showing most promise for establishment in temporarily flooded areas were knotgrass, reed canarygrass, prairie cordgrass, smooth seed paspalum, Florida paspalum, beaked panicum, Kanlow switchgrass, rice cutgrass, and the forb, creek willow. Kentucky fescue, Virginia wild-rye, western wheatgrass, smooth brome, knotroot bristlegrass, Indiangrass, and big bluestem showed poor to fair response to flooding but would probably be suitable in upper zones of detention pools where inundation would be less frequent and of shorter duration. (SWC 8-10(e2) Rev.)

4. Deep profile modification for soil and water conservation. At Pullman, Washington, plowing on eroded hilltop 3 feet deep resulted in increased water use and increased wheat and alfalfa yields. Soil on this hilltop is classified as Naff-Garfield, with compact B and C horizons similar to the Freeman soil. Deep plowing of Palouse soil with a 3-foot A horizon showed no wheat yield or water use response.

At Rockford, Washington, loosening and mixing Freeman silt loam with a backhoe 4 feet deep again increased soil moisture storage and utilization, and alfalfa yields. Alfalfa on the check area yielded 1.7 tons per acre as compared with 3.2 tons where the soil was loosened to a depth of 48 inches, each with adequate fertilization. The protein content was 12.8 percent for shallow tillage, and 15.2 percent for deep plowing. Plowing this soil 3 feet deep increased water use and yield of wheat and grass under high N and P fertility levels. Wheat yielded 70 bushels per acre where deep plowed, and 45 bushels under conventional plowing. Similarly, the yield of grass was increased 0.7 ton per acre. Deep-plowed soil provided 1.2 inches more water than the conventionally plowed soil. Deep plowing did not increase the yields of grass grown under low fertility. The alfalfa in the second year alfalfa-grass mixture on the Freeman soil apparently failed to nodulate effectively and the yield was not increased by deep plowing.

At Pendleton, Oregon, wheat yields were not significantly higher on the deep-plowed plots than on conventionally prepared seedbeds. Plot variability was high. (SWC 8-f1)

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AREA 9: MOISTURE CONSERVATION FOR THE EFFICIENT AND EFFECTIVE USE OF PRECIPITATION ON CROPS AND RANGELANDS

Problem. One of agriculture's major plagues in the United States is recurring drought. In 1963, the U. S. Department of Agriculture declared over 600 counties in some 18 states emergency areas because of drought. The Northeast States suffered from extensive drought in 1964. Inadequate moisture is the main factor limiting plant growth on cultivated land and rangelands in the Great Plains. Tree ring studies conducted in Nebraska show that 269 of the past 748 years were sufficiently dry to adversely influence crop production. Weather records at several locations in the Plains show that precipitation was below average 50 percent of the time. In most parts of the Great Plains, the frequency and amount of precipitation have significant social and economic consequences. If some means of reducing the large loss of water by evaporation and transpiration were available, the precipitation received would be more than adequate to support good plant growth and still provide sufficient water for other uses. The amount of moisture needed for actual plant metabolism is only a small part of that actually transpired by the plant. The amount of water used for transpiration is, in turn, usually less than the amount lost directly from the soil by evaporation.

The research in this area is directed toward the development of methods for increasing the infiltration of water into the soil profile, decreasing the evaporation of soil moisture, and controlling transpiration by physical and chemical means.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of moisture conservation, utilizing soil physicists, soil chemists, soil microbiologists, and agricultural engineers. At all locations, the work is done cooperatively with the respective state experiment stations.

The Federal scientific effort devoted to research in these areas totals 20 man-years. Of this total, 12 are devoted to factors influencing moisture storage; 5 to factors affecting the loss of water by evaporation; and 3 to factors influencing the use of moisture by crops.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in a substantial research effort directed toward better description and understanding of the principles involved in the movement of water and gases into, through, and from soils.

Studies are in progress in infiltration rates in relation to soil physical properties, vegetative cover, tillage, rate of water application and other factors. Water movement is related to gradients created by adsorptive and evaporative forces. Studies concern energy considerations and mathematical description of forces involved in water movement under both saturated and unsaturated conditions in the soil. Western regional research project W-68 and a North Central project NC-40 are concerned with aspects of water movement into and through soils.

Other research is concerned with factors relating to vapor movement of water in relation to soil and plant surfaces. Vapor losses, either as evaporation or transpiration account for a high percentage of the water loss from many agricultural areas. Studies are underway on overall relationships of climatic factors to vapor loss. The work includes measurement and evaluation of solar energy supply and dissipation in heating soil, air and vegetation and vaporization of water.

Work is in progress on development of tillage and management practices for increasing moisture-holding capacity of the soil. Possibilities are being explored for reducing vapor losses through manipulation of moisture at the soil surface, and through variations in plant spacing, density and orientation.

The total research effort at State experiment stations on moisture conservation problems is 33 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Factors Influencing Moisture Storage

1. Tillage. Concern about water use and resource development has sharply focused attention on the need for better estimates of water infiltration into agricultural lands. The extent to which infiltration estimates based on the numerical solution of the moisture flow equation represent that actually occurring in the field has been evaluated at Ames, Iowa. Results show that the relationship holds in a uniform soil without surface crusts or restricting subsurface layers. This finding represents real progress in that estimates for field soil moisture conditions for such soils can now be obtained in a few minutes with a computer, providing the data on the laboratory relationships are available. (SWC 9-c1)

In a study of the effects of tillage-induced conditions on net water storage in a Barnes soil at Morris, Minnesota, results showed that 2.1 inches of water had infiltered the soil prior to runoff on a plow-disk-harrow treatment as compared to 6.7 inches on the plow treatment. Infiltration rate on the plowed soil was still measurably higher after 2 hours of simulated rainfall. Further investigations will be directed towards the development of a mathematical expression for estimating infiltration which considers the boundary condition in a tilled soil. (SWC 9-c1)

Soil surface roughness and the porosity in the plow layer were shown to be closely related to the amount of water intake prior to incipient runoff in another tillage experiment at Morris. Roughness explained 76 percent and porosity 60 percent of the variation in the amount of water intake prior to the time of incipient runoff. Major changes in soil roughness and porosity occur during an intense rain, most of which take place before the start of mass overland water flow. On Barnes loam, 80 percent of the total change in plow-layer porosity and 70 percent of the total change in random roughness for the plowed and plowed-disked-harrowed treatments occurred by the time runoff started. These data suggest that additional soil moisture can be stored if the plow-plant method of seeding corn is used in lieu of conventional methods. This information, though based on a relatively short period of study, should be immediately useful to areas of the Corn Belt that are plagued with crop damage from drought. (SWC 9-c1)

2. Fallow methods. In order to give Great Plains soils maximum protection from wind erosion, farmers frequently delay tillage operations on summer-fallowed wheatlands until there is an abundance of weed growth rather than keep the land free from weeds all through the fallow season. This erosion control fallow method has not received widespread usage because the farmer has been concerned about the possible reduction in wheat yields. Wheat yields on delayed and conventional fallow plots were compared at Bushland, Texas, with long-time records from 12 Great Plains dryland experiment stations where the two types of fallow systems were practiced. A total of 223 location-years of data at seven dryland experiment stations showed an average spring wheat yield of 19.3 and 19.6 bu./acre on clean and delayed fallow, respectively. A total of 114 location-years of data gave an average winter wheat yield of 17.6 and 18.6 bu./acre for clean and delayed fallows, respectively. These data adequately demonstrate that the Great Plains' wheat farmer can reduce his tillage operations on fallow land by one-half and not sacrifice yields. (SWC 9-e1)

One of the most effective tools in controlling wind and water erosion on the Great Plains is a tillage system that keeps the straw on the soil surface. Research information on the soil moisture relations under straw residue is difficult to obtain and what is available is contradictory. Equipment now available to researchers, which includes the neutron probe, permits an accurate evaluation of small changes of soil moisture conditions. At North Platte, Nebraska, moisture storage during a wet and cold year was increased by as much as 5 inches by leaving the residue on the soil surface following harvest as compared to incorporating the residue into the soil. Most of the increase was the result of snow trapped in the standing stubble. Grain yields, however, were reduced by the straw residue. During the heavy rainfall months of May and June at Sidney, Montana, 0.5, 0.9, 2.4, and 2.8 inches of water were stored under 0, 1,500, 3,000, and 6,000 pounds per acre of residue, respectively. During the remainder of the season, the storage on all plots was about equal. As a result of the

increased storage of soil moisture, wheat yields on the residue treatments were 4 bushels higher than on the treatments that had no residue. Moisture storage under residue treatments at Akron, Colorado, was increased by 0.7 and 1.7 inches during a 14-month fallow period under the 3,000- and 6,000-pound-per-acre treatments. Wheat yields were increased 3.2 bushels per inch of water stored. While the above data do not give a complete understanding, they do represent a good beginning and help to define the areas where the emphasis should be placed in future studies. (SWC 9-d1)

Water intake studies conducted on three small native rangeland watersheds at Cottonwood, South Dakota, showed that the intake was directly related to intensity of grazing. The intake rates for the second 30 minutes of a 60-minute simulated rainfall were 0.70, 1.22, and 2.72 inches per hour on heavily, moderately, and lightly grazed pastures, respectively. These differences were attributed to the increased amounts of surface mulch on the lighter grazed pastures. These data suggest that some of the benefits of good pasture management can be attributed to increased intake of rainfall on the lightly grazed treatments. (SWC 9-d1)

3. Land forming. Investigations to evaluate the benefits from level bench systems continued at several locations in the Great Plains. Studies at Mandan, North Dakota, on level bench systems showed that the yield of alfalfa and bromegrass can be increased from twofold to threefold on leveled benches compared to the untreated area. Little yield differences occur on benches with and without contributing areas. Soil moisture values indicate that the main benefit of the benches is better management of the water from snowmelt. At Akron, Colorado, 10 inches of water were stored in the soil on the benches from one June storm. As a result of the increased stored moisture, yields of grain and forage sorghum were more than doubled and corn fodder and grain yields were increased tenfold as compared to the unleveled check. Future studies will be directed to the development of systems that will best fit the many soils and slope variables common to the Great Plains. (SWC 9-d1)

4. Snow management. About one-fifth of the annual precipitation in the Great Plains comes as snow, a high percentage of which is lost because the snow accumulates in road ditches and along fence lines. Knowledge of the factors that influence the movement of snow and soil by wind, derived from wind tunnel studies at Manhattan, Kansas, can now be evaluated in the field. Double sorghum rows planted 36 feet apart at Akron, Colorado, increased the water stored an average of 1.1 inches over the area. Wooden snow fences spaced 60 feet apart accounted for an average gain of 4 inches. Of the snow accumulated in drifts, 82 percent were later accounted for by soil moisture measurements. Wheat yields on the area protected by barriers were 3.5 bushels per acre higher than on the area with no protection. (SWC 9-d1)

5. Ridge covering. During the year, studies continued at two locations to further evaluate the benefits of covering the ridges between row drops with plastic films. Corn yields at Fort Collins, Colorado, for treatments where all of the runoff from impervious ridges between rows 6.5 feet wide was diverted into two rows planted 1.5 feet apart were 36 bushels per acre compared with 4 bushels per acre for the conventional 3-foot row spacing with no runoff diversion. When the runoff water was diverted into two rows from a ridge between rows 10.5 feet wide, corn yields were 25 bushels per acre. (SWC 9-d1)

For the period 1961-1964 at Mandan, North Dakota, average yields of field beans, Russian wildrye, tomatoes, cantaloupes, soybeans, safflower, sweet corn, and field corn have been significantly higher on treatments with covered ridges as compared with uncovered ridges. Average sugar beet yields for the period were 13.6 tons per acre on the ridge-treated plots as compared with 10.7 on the untreated plots. The system of ridge coverings gave yield increases at all locations tested, but considering the present market prices of the required materials and the crops produced, it appears to be economically feasible only on high cash value crops. (SWC 9-d1)

B. Factors Affecting the Loss of Water by Evaporation

1. Chemical treatment. The search for chemical treatments that will reduce evaporation from the soil surface continues at Fort Collins, Colorado. Of the chemicals tested, the chlorosilane compounds were very effective in waterproofing and in suppressing evaporation from the surface soil. Twenty days after treating the surface 5 cm. of soil, the total water evaporated was about 10 percent that from an untreated soil. However infiltration of water into the treated soils was almost nil, which from a practical standpoint, limits the use of this chemical. Chlorosilane may be useful in waterproofing soils to induce runoff from areas where water harvesting is desired. (SWC 9-d1)

2. Moisture loss from bare fallow. In any moisture deficient area, the amount of water lost from the soil under bare fallow as compared to surfaces protected by mulches is a practical question of real significance. At Weslaco, Texas, moisture depletion from the surface 2 feet of the soil profile during 1964 was 2.6 inches under bare fallow and 0.4 inch under a 0.6-inch mulch of mortar sand. There was an increase of 0.5 inch under a 2-inch mulch of cotton burs. Average weekly soil moisture suction readings at a depth of 20 inches were 126, 105, and 109 cm. water for the bare fallow, sand and cotton bur mulches, respectively. Monthly averages of daily maximum temperatures at a 4-inch soil depth were highest under the sand mulch. Even though soil temperatures were highest under the sand, it apparently formed an effective barrier against water vapor transfer. The low moisture depletion under the mulches illustrates the effectiveness of these materials in controlling evaporation from the soil surface. (SWC 9-e1)

3. Evaporation from summer rains. The question of how much of the moisture from summer rains in the Great Plains is stored in the soil and how much is lost by evaporation remains unanswered. At Akron, Colorado, eight simple and inexpensive lysimeters 1 meter square were designed and installed to study daily water loss under various crop-soil conditions. Initial studies with these lysimeters, together with measurements of net radiation, indicate that the evapotranspiration from a partial buffalograss cover is equal to about one and one-half times the equivalent net radiation after a widespread summer rain. These data show that summer rains in the Great Plains are frequently ineffective because of high evaporation rates brought about by large amounts of stored heat in the soil. Plans are being made to expand and intensify these studies during the next growing season. (SWC 9-d1)

C. Factors Influencing the Use of Moisture by Crops

1. Soil texture. The influence of soil texture on the efficiency with which the crop uses water has been of interest to dryland farmers for some time. At Riverside, California, the moisture status of soils with widely different textures, which had been brought to field capacity before planting barley, was closely followed during the growing season. The total moisture use in the 5-foot soil profile varied from 7.0 inches in a loamy sand to 20.9 inches in a clay. Barley yields were 300, 1,320, 5,430, and 5,090 pounds per acre for a Hanford loamy sand, sandy loam, very fine sandy loam, and an Arcilla clay, respectively. Moisture use efficiency values (pounds of grain produced per inch of water used) were 295 pounds per inch for the very fine sandy loam and the clay as compared with 148 for the sandy loam and 43 for the loamy sand. While the above data are no claim to a complete understanding of the moisture relation of soils of different textures, it does suggest that in areas of limited rainfall soil texture has to be taken into consideration in choosing the most desirable cropping and fallow systems. (SWC 9-g1)

2. Moisture levels. At Fort Collins, Colorado, yields of sudangrass were compared at several preseason established moisture levels in an experiment designed such that advective energy was kept at a minimum. Yields were 1,035, 3,266, and 5,728 pounds per acre at the 6.7- (low), 10.5- (medium) and 20.7- (high) inch water use levels, respectively. The water use efficiency values (pounds forage per inch water used) were 310 pounds per inch at the medium moisture level as compared to 280 at the high and 154 at the low moisture level. Late season growth was greatest on treatments which had available moisture deep in the profile. These data show that the plant makes the most efficient use of water at some level below the condition of unlimited moisture. (SWC 9-d1)

3. Crop varieties. The possibility of increasing the efficiency of soil moisture use by the selection of the best varieties within a species has recently become of interest to scientists and farmers. Results of field

experiments at Pendleton, Oregon, in which Gaines winter wheat was compared with the standard varieties Omar and Brevor, showed that the Gaines outyielded the other two varieties by 24 percent while using the same amount of available soil moisture. Further studies will be directed to determine if there is a stage of growth where the moisture use differs for these three varieties. (SWC 9-f1)

In a dryland water-use efficiency field study at Sidney, Montana, Russian wildrye planted in 30-inch rows produced 402 pounds of forage per inch of water used as compared to 311 pounds for intermediate wheatgrass and 125 for western wheatgrass in the same row width. The water-use efficiency values were highest at the 30-inch row width and the lowest at the 60-inch width. The data from these experiments suggest that the plant breeder in releasing improved varieties has contributed a great deal to the efficiency with which water is used in American agriculture. Future water use research should include cooperative studies between the soil scientist and the plant breeder. (SWC 9-d1)

4. Transpiration control. The Division is continuing the search for new chemicals to reduce the loss of water by transpiration. Preliminary studies at Akron, Colorado, indicate chemical treatment of plants to induce stomatal closure may be promising. Sorghum yields were increased by 18 percent when the plants were sprayed every two weeks with succinic acid. No differences in moisture use were detected. (SWC 9-d1)

5. Fertilizer. In a continuing study to evaluate the influence of nitrogen fertilizer on the moisture use at Pendleton, Oregon, fertilized wheat removed 1.2 inches more water from the 10-foot soil profile than the nonfertilized wheat. The greatest difference in moisture extraction occurred in the 6- and 7-feet depths. For the 3-year study period, the application of nitrogen fertilizer increased the relative water use efficiency about 20 percent. Each year there was evidence that fertilized wheat extracted more water at profile depths greater than 5 feet as compared to unfertilized wheat. These data are of particular importance under conditions of limited water supply where full exploitation of soil water is of greatest significance. (SWC 9-f1)

6. Water table. In many dryland agricultural areas underlain with a shallow water table, the moisture needs of many crops are partially satisfied by the water table. At Raymondville, Texas, grain sorghum yields compared at several moisture levels were inversely related to the depth of the underground water table at seeding time. For each foot the water table dropped, grain yields were reduced by approximately 400 pounds. Moisture data collected in the experiment suggest that a substantial amount of water was used from water tables up to 8 feet deep. (SWC 9-e1)

7. Cropping. Many scientists have assumed that with the same moisture conditions the profile moisture depletion under a cropped soil was quite

different from that in a bare soil. At Weslaco, Texas, in a study designed to evaluate the moisture depletion pattern for fallow and growing cotton, the moisture depletion totaled 28.8 inches for the growing season on the cotton cropped land as compared to 11.2 inches for the bare fallow land. Maximum depletion during a 30-day drying period was 6 inches of water for the cotton as compared to the 2.4 inches for the fallow. Even though total depletion differed widely for the two systems in both cotton and fallow plots, the water use from the surface foot accounted for 50 percent and depletion from the 1- to 2-foot depth an additional 25 percent of the total. These data, though incomplete, suggest that the presence of a crop increases the withdrawal of water, but not the distribution of the withdrawal within the profile. (SWC 9-e1)

In dryland areas producing small grain, drills with different row widths and disc design have been tested with limited success for the past two decades. Row spacings of 7 inches, 14 inches, or combinations of 7 and 14 inches, did not markedly change grain yield or moisture-use efficiency of dryland wheat grown under moisture stress conditions in a field study in Antelope Valley, California. Dry matter production and green leaf area over much of the growing season were higher with a 7-inch than with a 14-inch row spacing. Furthermore, a lower planting population density in the 7-inch rows resulted in more tillering and larger numbers of seed heads. However, the moisture supply was not sufficient to sustain the added vegetative growth, kernels were smaller, and consequently, the final grain yields were not increased. These data give some insight as to the factors that tend to make for the same yield regardless of the planting system used. (SWC 9-f1)

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AREA 10: SOIL PROPERTIES, PROCESSES, AND MANAGEMENT IN RELATION TO THE CONSERVATION AND EFFICIENT USE OF LAND AND WATER RESOURCES

Problem: The soil is the source of the nutrients required for plant development. When chemicals are applied to the soil, they usually react with the soil before the plant uptake process begins. The nutrient ion finally is found in the top of the plant where it performs its metabolic function. To reach this end point, the ion passes through various chemical reactions, most of which are not understood.

Soil tilth and structure control many of the responses of the plant to soil management. All too often, visual improvement of the physical properties of the soil has been observed in the field, yet these physical attributes cannot be quantitatively described because of a lack of methods and procedures. The research progress on soil tilth is hampered by a lack of understanding of the forces involved in holding soil particles together in stable crumb structure. If an understanding of the factors was improved, our scientists could develop practical methods for exerting a real influence over the structure of our soils.

Fertilizer use in this country is presently well over 3 million tons per year. With low-cost commercial fertilizer now available, our farming has become much more efficient and economical. Fertilizer practices still remain largely empirical, however, and nutrient imbalance is common.

Large amounts of pesticides and growth regulators are used. These compounds are either applied to the soil or ultimately reach the soil. The fate of these compounds in the soil must be known in order that the residual amounts may be predicted. Soil organic matter is constantly undergoing changes as a result of the activities of micro-organisms. The role of the soil flora and fauna in the mineralization of organic materials and chemicals added to the soil is not understood.

USDA AND COOPERATIVE PROGRAM

The Division program in this area involves microbiologists, chemists, physicists, and plant physiologists working on basic and applied problems associated with developing principles for soil and water conservation. The Federal scientific effort devoted to this research totals 97 professional man-years. Of this number, 32 are devoted to nutrient requirements--uptake and balance; 23 to soil chemical properties; 33 to tillage, residue management and cropping systems; and 9 to soil microbiology.

PROGRAM OF STATE EXPERIMENT STATIONS

A very substantial research effort is in progress at the State experiment stations on fundamental and applied aspects of soil properties, processes, management, and classification. The studies cover cation and anion fixation on clay mineral surfaces, exchange processes and rates between solid and liquid phases, activation energy for ion movement, the mechanisms of fixation of potassium, ammonium and other ions, and a variety of related processes. Other studies concern the rate and mechanism of nutrient uptake by plant roots as influenced by nature of the nutrient, ion balance, oxygen and carbon dioxide tension, temperature and other factors.

Work is in progress on physical, chemical and mineralogical characterization of soils in support of classification and survey work. Studies seek better understanding of clay mineral development from parent materials, mineralogical characterization of sand, silt and clay fractions and the relation to soil structure and profile development. Investigations on soil physical properties seek better understanding of the mechanism and forces binding soil particles into aggregates, the role of clay in aggregate formation, the nature of interaction between organic matter and silicate minerals, and the influence of pressure and load conditions on particle behavior. Soil microbial investigations concern nitrogen fixation and transformation, factors influencing legume inoculation, organic matter accumulation and decomposition, and environmental factors influencing microbial processes.

Research is underway on nutrient relationships of soils and methods of determining nutrient availability. Studies are in progress on trace element chemistry and nutrition of specific crops. Lime reactions and relationship to nutrient availability are being investigated. Interactions of fertilizer needs and applications with other soil and crop management practices are under study.

Several State stations have work in progress on the behavior and fate of pesticides and radiation isotopes that reach the soil from various sources.

Cooperative research between several States is in progress under the following regional projects: NE-11 on soil aeration and root development; NC-55 on soil organic matter; NC-56 on soil structure; W-66 on the nature and control of soil crusts; S-60 and W-87 on clay mineralogy; S-62 on fate of pesticides in soils; S-52 on soil testing; and S-51, NE-39, and W-85 on the loss, retention, and transformations of soil nitrogen.

The total research effort of the State experiment stations on soil properties, processes, management, and classification is 427 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Nutrient Requirements--Uptake and Balance

1. Recovery of applied nitrogen. Because of the increased concern about nitrogen contamination of surface and ground water supplies, studies are continuing on the biological and chemical factors that determine the loss of nitrogen by volatilization or deep percolation. At Laramie, Wyoming, in laboratory studies of factors involved in low nitrogen recovery from grassland soils, ammonia volatilization losses from urea were 7 percent from 50 pounds, 12 percent from 100 pounds, 20 percent from 200 pounds, 23 percent from 300 pounds, 26 percent from 400 pounds, and 25 percent from 500 pounds of nitrogen per acre applied to a bare soil in a closed system. Nitrogen loss through ammonia volatilization was found to be proportional to air flow and subsequent depletion of moisture. (SWC 10-d2)

At Huntley, Montana, sugar beets and bromegrass were grown for 2 years in an experiment with 3 moisture regimes and 4 nitrogen fertilizer levels. Nitrogen applications were 0, 100, 200, and 400 pounds of N per acre. Moisture control levels were such that moisture use was about 20, 40, and 75 percent of the available moisture in the most active area of root activity. Utilization of fertilizer N was affected very little by differences in moisture within the range tested. The 2-year average N use efficiency of the 100-pound N rate was 91 percent by grass and 75 percent by beets. Efficiency of use of the 400-pound N rate averaged 50 percent by both crops. Considerable N was carried over from one year to the next and was available for use by subsequent crops, but none were lost by deep percolation. (SWC 10-d2)

2. Mineralization of nitrogen. At Corvallis, Oregon, basic studies concerning the chemical nature of soil organic matter are continuing. Analysis of the organic matter separated from 11 soils indicates that the percentages of various amino acids released by hydrolysis in 6 N hydrochloric acid were similar for all soils studied. Sixteen amino acids made up the major portion of the total hydrolyzable acidic and neutral amino acids measured. These studies indicate a similarity in the organic matter of different soils developed under widely different conditions of climate and vegetation. (SWC 10-f3)

Although studies concerned with the decomposition of organic material in soils have been going on for several decades, the methodology involved still leaves much to be desired. Little is known about the extent to which physical, chemical, and biological factors influence organic matter decomposition in soil. In a study at Fort Collins, Colorado, of factors affecting rate of decomposition of added organic residues in soil, CO_2 measurements were made for laboratory soil treated with various amounts of residue and incubated in various volumes of soil. With soil volume constant, the percentage decomposition of an organic residue added to soil

was inversely related to the rate of addition. When the rate of residue addition was varied, the percentage decomposition was directly related to rate of addition and inversely related to soil volume. With rate of residue addition constant but with soil volume variable, percentage decomposition was inversely related to soil volume. All attempts to link the variable percentages of decomposition to the type of aeration employed were negative. These data suggest that shortage of microbial living space, which has been advanced by some scientists, does not appear responsible for such unfavorable influences of rate and volume on decomposition as were observed. The rate and volume effects on soil respiration do not appear wholly to be due to insufficient oxygen. With increases in rate of residues applied and in the volume of soil used, some shift in the soil flora and fauna appears to take place in response to increasing carbon dioxide content of the soil atmosphere or in response to the presence of some toxic volatile or oxidizable product of decomposition. These investigations have not been carried to a point where a meaningful synthesis can be made. However, from the results obtained, it would appear that many of the concepts concerning organic matter decomposition in soil are inadequate. (SWC 10-d2)

One of the deterrents in knowledge of available nitrogen in soils is the analytical methods that are available. In an attempt to find better procedures, an aerobic fermentation method and an alkaline reduction method using Devarda's alloy were compared on 65 western soils at Fort Collins, Colorado. Results suggest that both methods measured a common labeled pool of organic nitrogen in the soil. Further research on the correlation of these methods to nitrogen uptake will be required. (SWC 10-d2)

The source for the large amount of organic nitrogen that accumulates in mountain meadow soils, which were formerly very low in nitrogen, has long been a mystery. Symbiotic fixation by nodules on the roots of native legumes is one possible source, but fixation of nitrogen from the air by free-living organisms in the wet environment has been suspected. Nitrogen fixation from air containing the heavy isotope N^{15} was determined for wet mountain meadow sod mats. Sod mats with nonleguminous plants that were photosynthetically active and operating under aerobic conditions fixed less than 5 pounds of N per acre in 120 days. However, a sod mat with plants in the dark, and a rapidly developing anaerobic atmosphere, fixed approximately 50 pounds of N per acre in 120 days. From these data, it appears that considerable N can be fixed by anaerobic organisms under mountain meadow conditions. Further studies under wet meadow field conditions will be required before the significance of this possible source of nitrogen will be known. (SWC 10-d2)

3. Nutrient requirements for various crops. Any crop grown from seed has an initial period of very slow growth. The small seedling top during the several weeks of early growth accounts in part for low efficiency of solar

energy utilization and high percentage of water loss by evaporation. Cotton seedlings were studied in the greenhouse at Riverside, California, using various nutrient and temperature levels, and in the field at Brawley, California. Optimum concentrations of nitrogen and phosphorus in young seedlings, as established in the greenhouse experiment, were compared with concentrations obtained in the field-grown seedlings. In the greenhouse, seedlings were larger within 2 weeks after planting than in the field after 6 weeks, even though soluble nitrogen and phosphorus levels in all plants were similar. Since field-grown seedlings did not respond to additional nitrogen and phosphorus applied as nutritional sprays, it was concluded that nutrients were not limiting factors and that growth rate in the field was limited by environmental conditions. Below optimum soil and air temperatures appeared to be the main environmental factors responsible for the limited early growth of seedlings in the field. (SWC 10-g1)

The problem of controlling blowing sand in arid rangelands has been studied near Hardesty, Oklahoma. Nitrogen and phosphorus fertilizer stimulated the growth of native "sandbinding" grasses, and thus stabilized active sand dunes. From these data, it appears that many of these areas can be revegetated by fertilizing the existing species. (SWC 10-e2)

In studies conducted on calcareous subsoils in the Columbia Basin near Prosser, Washington, large residual effects were measured in the 1964 crop from phosphorus fertilizer applied in 1962 and 1963. The carryover was measured in yield and P content of sudangrass forage. Soil tests for available P at the beginning of the season offered a practical and reliable means for evaluating the carryover from previous years' applications. (SWC 10-f2)

The response of lettuce in the Imperial Valley in California, to nutrients applied as commercial fertilizer was compared to treatments receiving commercial fertilizer plus manure. Yields on the treatments receiving manure were 25 percent higher than those which received commercial fertilizer alone, although the amount of nutrient applied was the same in both cases. No beneficial residual effects were obtained from the manure applications when a crop of unfertilized grain sorghum was grown following the lettuce crop. These results suggest that the large quantities of manure that accumulate from feedlot operations in this area might be profitably used in vegetable production. (SWC 10-g1)

Experiments have continued at State College, Mississippi, to compare a cytoplasmic male-sterile hybrid corn strain (cms F44 X F6) with its fertile counterpart (F44 X F6). Experimental evidence suggests that the higher grain yields in the sterile strain can be attributed to the sterile plants being capable of utilizing the solar energy, soil water, and nitrogen more effectively than the fertile strain. Cation and anions measured in the leaves at several moisture tensions and at several stages of growth indicate that the cytoplasmic influence on ion uptake is quite different for the two strains. (SWC 10-b3)

A study was initiated at Watkinsville, Georgia, to determine if maintaining certain levels of NO_3-N in the cotton petiole during the growing season would allow for maximum yields. Results showed that when the NO_3-N content of the leaves was maintained above 2,000 ppm. throughout the season, seed cotton yields were increased by 20 percent. The largest decline in nitrate levels of the petiole occurred during the blooming stage. These data suggest that maintaining the nitrate level in the petiole above 2,000 ppm.is not only desirable, but profitable. (SWC 10-b3)

Studies have continued at the U. S. Pasture Laboratory at University Park, Pennsylvania, on factors responsible for the poor persistence of alfalfa in grass legume mixtures. Data from a limited number of field experiments indicate better persistence of alfalfa in association with orchardgrass when the alfalfa and grass were seeded in alternate 7-inch rows than when seeded solid. Root growth of both species was greatly increased by phosphate fertilization. (SWC 10-a2)

4. Phosphorus diffusion. Studies at Fort Collins, Colorado, on phosphorus nutrition have included the further use of mathematics in solving diffusion problems. A dimensionless variable curve was constructed which applied for wide ranges in time and root radius. Methods were developed to evaluate the role of diffusion as related to the nature and properties of root systems. The relative contribution of root hairs and main roots to the total uptake of nutrients can be ascertained by these methods. The calculations showed that for equal surface areas, root hairs are capable of absorbing four times as much P as the main root. It was also possible to measure from diffusion equations the effective soil volume from which the root withdraws P. These values were used to determine whether the rate of release of P from the solid phase to the solution governs the uptake of P by roots. The results indicate that rate of release was not a limiting factor in the systems. Knowledge of the factors that control phosphorus availability can now be used to develop recommendations for farmers on different soils and for different crops. (SWC 10-d1)

In the same laboratory at Fort Collins, results showed that the self-diffusion coefficients of P in Apishapa silty clay loam (calcareous) ranged from 0.4×10^{-7} to 15.5×10^{-7} cm^2 sec^{-1} as the volumetric moisture content increased from 0.22 to 0.55, or as the soil moisture suction decreased from 6 to 0.1 bar. These changes in diffusion coefficient account for most of the decrease in uptake of P by roots as related to increased moisture suction. (SWC 10-d1)

Diffusion coefficients for P in soil have been measured by two independent methods and also by calculations from chloride diffusion measurements. The values from each method agreed reasonably well. From the diffusion coefficient of P in soil, a value was calculated for the diffusion coefficient of P in water, i.e., 5.1×10^{-6} cm^2 sec^{-1} when the

volumetric moisture content was 0.55 (100 cm. of water suction). This value compares very well with the diffusion coefficient, 5.0×10^{-6} cm^2 sec^{-1}, reported in the literature for P in water. This agreement constitutes good evidence that the soil-water properties affecting diffusion of P were taken into account adequately. (SWC 10-d1)

In another study at Fort Collins, Colorado, procedures have been developed for the separation and quantitative determination of the major phosphate products in corn roots. These have provided the most complete description of the sequence of incorporation of newly absorbed phosphorus in plant roots so far available. The data provide clear evidence for phosphorus accumulation into inorganic pools within the root at higher concentrations than the external solution. (SWC 10-d1)

A study of phosphate movement in two calcareous soils at Tucson, Arizona, indicated that phosphorus was fairly mobile in a calcareous sand but not in a clay loam. The water-insoluble source, dicalcium phosphate and rock phosphate, did not move a measurable amount in either soil. These data are in agreement with the studies at Fort Collins and should be most helpful in predicting the phosphorus requirements of various crops in the Southwest. (SWC 10-g1)

5. Micronutrients. In 1963, results from a field study conducted near Prosser, Washington, indicated that corn following 3 years of sugar beets was severely zinc deficient, but that corn following 3 years of sorghum was not. Results of further field studies indicate that the effect of sugar beets in inducing zinc deficiency on subsequent crops is not long lasting. Red Mexican beans, which are zinc sensitive, were grown without any zinc deficiency symptoms in 1964 on treatments where zinc deficient corn followed sugar beets in 1963. (SWC 10-f1)

Research on zinc nutrition of beans and potatoes conducted at Prosser, Washington, and Beltsville, Maryland, indicates that zinc deficiency associated with high levels of phosphorus in these plants is a result of an imbalance between zinc and phosphorus in the plant rather than a phosphorus interference with zinc absorption. Field study results indicate that even under extreme conditions of zinc deficiency, 10 pounds of zinc per acre applied broadcast before plowing completely corrects zinc deficiency. Higher rates of application increased the zinc concentration in the foliage but did not increase bean yield. (SWC 10-f1)

At Fort Collins, Colorado, studies are continuing on the influence of P on Zn and Fe deficiency in an attempt to determine the ratios where adverse effects could be expected. Damaging effects were noted when the P/Fe concentration ratio in the plant exceeded 60 and the P/Zn concentration ratio was greater than 300. Adverse effects were also noted when the Fe/Zn concentration ratio in the plant was below 1.5. These studies indicate a need for caution in using multiple-component fertilizer, since indiscriminate use may induce various nutrient imbalances. (SWC 10-d3)

Studies at the U. S. Pasture Laboratory at University Park, Pennsylvania, on the distribution of macro- and micro-mineral nutrients in ladino clover as affected by phosphorus nutrition emphasized the importance of physiologic age on leaf mineral composition. In these studies, P and Zn were higher in immature leaves than in older leaves, whereas Ca, Mg, Mn, and B were higher in older leaves. Potassium and copper contents of leaves were largely independent of age. (SWC 10-a2)

At Fort Collins, Colorado, laboratory and greenhouse studies continue to show that the sulfur status of soils is related to the decomposition of organic matter. In the presence of adequate nitrogen and phosphorus, the rate of decomposition of straw added to a Williams loam depended on the sulfur content of the straw, which in turn, depended on where the straw was produced. Growth of wheat in a greenhouse experiment with a nitrogen- and phosphorus-fertilized Weld loam depended on the sulfur content of the straw incorporated into the soil. The addition of a low-sulfur straw reduced the growth of wheat unless fertilizer sulfate was used. These data suggest that a sulfur deficiency may be one of the factors responsible for the loss of organic matter in Plains' soils and for the depressing effects of residues on crop yield that have been observed. (SWC 10-d3)

The distribution of micronutrients among the soil minerals has never been understood. Data collected from an experiment in Poland concerned with the distribution of micronutrients in residual soils developed on igneous and sedimentary rocks show that the main factors operative in influencing the geochemical distribution of elements in profiles are the clay contents and heavy minerals. The highest concentration of the trace elements was found in the silty clay and coarse clay fractions. These correlations complement nicely the work being done on micronutrient problems in this country. (E21-SWC-7)

B. Soil Chemical Properties

1. Soil acidity and plant growth. At Auburn, Alabama, studies have been continued to determine the specific chemical factors responsible for inhibition of root growth in acid subsoils of the Southeast. Hydrogen ion concentration *per se* was found not to be a factor in initial cotton radical elongation at pH levels above about 4.25. However, subsequent secondary root development appeared to be much more sensitive to pH. Low levels of calcium did not limit root growth in acid subsoils when the surface soil was favorable for total plant growth. Calcium availability in a kaolinitic and a montmorillonitic subsoil was quite different when expressed as exchangeable calcium. However, when expressed as a ratio of calcium to total cations, the critical exchangeable calcium levels were equal in the two subsoils. A ratio of about 0.2 was critical if solution cultures or widely different subsoils were used as the subsurface medium. Root damage due to aluminum toxicity in acid subsoil materials may best be understood as a function of the chemical activity of the soil solution aluminum.

Toxic concentrations of aluminum in terms of molar activity were very similar for subsurface media of nutrient solutions and widely different subsoils. Identification of the above factors has provided a basis for better assessing the adverse influence of acid soil on the growth of plant roots. (SWC 10-b6)

At Beltsville, Maryland, continuing studies on the factors affecting limestone efficiency have substantiated the earlier observation that limestone particles do react with soil constituents in such a manner as to form a coating on the surface of the particle. This coating generally results in an increase in the surface area of the particle, but the solubility rate of the particle may be either increased or decreased, depending on the composition of the coating. If the major constituent of the coating is an iron or aluminum compound, the solubility rate is increased. However, if the major constituent is a phosphorus compound, the solubility rate is drastically reduced. Current studies have shown that particles recovered after coming to equilibrium in Crystal Lake peat, which was high in phosphorus, were coated with a thin porous coating of triclinic $Ca(H_2PO_4)_2$ that reduced the solubility rate of the limestone by as much as 30 percent. Further studies are being directed toward determining the influence of these coatings on the diffusion rate of Ca in selected soils. (SWC 10-aB7)

At Watkinsville, Georgia, a study was initiated in 1964 to determine why Coastal bermudagrass responded to lime after applying nitrogen fertilizer for several years. The addition of 1 ton per acre of calcium sulfate (gypsum) in 1964 consistently and significantly increased forage production on plots fertilized several years ago with various lime rates. Since calcium sulfate is a neutral salt and the pH of the soil was not altered, apparently yield response was not due to a change in hydrogen ion concentration in the soil solution. Additional work is under way to determine if either calcium or sulfur is the causal factor. (SWC 10-b3)

Studies at Beltsville, Maryland, on the aluminum tolerance of plants have been concerned with the pH-changing abilities of the roots of different plant varieties. Differential Al tolerance among varieties of barley and wheat was attributed, at least in part, to the effects of plant-induced differential pH changes on the solubility of Al in the growth medium. Aluminum-sensitive wheat and barley varieties had higher cation exchange capacities of roots than Al-tolerant varieties. According to the Donnan principle, this could result in relatively greater uptake of Al by the roots having the higher exchange capacity. (SWC 10-aB8)

2. Soil pesticide complexes. The correlation between the adsorption of herbicides and the physical and chemical properties of 18 different soils is being studied at Beltsville, Maryland. For the group of soils studied, adsorption of simazine and atrazine from aqueous solutions was not significantly related to soil pH. However, adsorption was significantly related

to percent clay, organic matter, and titratable acidity. Physical-chemical considerations have led to the conclusion that this adsorption is by proton association. The percentage adsorption was reciprocally related to the energy of exchange of hydrogen for simazine and independent of the basic saturating cation. Simazine was absorbed to a greater extent than atrazine from solutions of like concentrations. (SWC 10-aB4)

The adsorption characteristics of triazine pesticides were determined in inorganic, organic, and soil mixtures at Watkinsville, Georgia. Several polar solvents showed promise of being extractants for the triazines. Adsorption is low on alumina and silica, but very high on charcoal. (SWC 10-b5)

Instrumentation for pesticide studies and method evaluation for analysis has been accomplished at Fort Collins, Colorado, during the year. The objectives of the research will be to study the movement of pesticides in soil, their movement over land surfaces, and methods of accelerating their decomposition in soils. Also included will be a study of the effect of pesticides on soil metabolism and enzymatic activity, the movement of pesticides in the soil by diffusion, and the physical chemistry of their adsorption on the mineral fractions and humus components of the soil. (SWC 10-40(d7))

In a continuing study in Spain on the relation of the retention of pesticides to clay properties, light, and temperature, results show that the catalytical decomposition of DDT into DDE, which is a nontoxic substance, is greater with homoionic acid samples than with natural samples. Homoionic acid samples retained the DDT with greater strength than regular samples. In studies on the influence of light on decomposition, 10 percent of the DDT retained in the clay was transformed to DDE after being exposed to ultraviolet light for 100 hours. Movement studies revealed that after 200 hours, DDT diffused throughout a column of clay and appreciable quantities of DDE appeared as a result of catalytic decomposition. (E25-SWC-7)

3. Radioactive fallout. Studies concerned with minimizing the potential hazards of radioactive fallout on soils and plants are being continued at Beltsville, Maryland. In a field study at Bushland, Texas, the uptake of radiostrontium by grain sorghums was reduced more than twentyfold by burning the plant roots at a depth of 20 inches with sodium carbonate. Similar results were obtained with soybeans at Beltsville. In treatments which received abundant nutrients and water in the top foot of soil, the uptake from layers of radiostrontium at less than 2 feet was not appreciable. The methodology for burying radiostrontium and sodium carbonate at depths up to 30 inches with a moldboard plow will receive further investigation. (SWC-AEC-0-0-1)

Also under study has been the simulation of deposition of radioactive materials in rainfall. Results show that deposition occurred soon after the rain started to fall and that the deposits were almost completely washed off by the end of a large rain. (SWC-AEC-0-0-1)

C. Tillage, Residue Management and Cropping Systems

1. Soil structure. Studies to isolate the organic and inorganic materials that serve as binding agents in the stabilization of soil crumbs are continuing at St. Paul, Minnesota. Work during the past year has shown that ion exchange chromatography techniques employing double columns coupled with paper chromatographic and electrophoretic methods have proved most effective in characterizing polymers found in clay complexes. Results from these experiments, though not complete, have shown that reactive groups of the carboxyl type most affect the strength of crumbs formed. The question of what effect clay minerals have on bonding strength remains to be resolved. (SWC 10-c3)

Aggregate size has often been observed to be important parameter affecting plant growth and moisture relationships. Reliable methods for determining aggregates have not been developed. In a study at Morris, Minnesota, on the effect of aggregate size on the water-holding capacity of the soil, a method was developed for determining aggregate diameter and distribution throughout the growing season in the field. Tillage treatments influenced the mean diameter and size of aggregates. During the 6-week period after planting, the range of aggregate diameter found in the soil decreased while the bulk density increased. The bulk density of the 0- to 3-inch layer increased as the dispersion of aggregates increased. The most water was stored when aggregates with the same mean diameter had the greatest dispersion. These data add materially to our understanding of the effect of soil structure on the water-holding capacity of the soil. (SWC 10-c2)

In studies at Morris, Minnesota, changes in pore size distribution over an entire moisture range are being studied. A method has been developed which makes it possible to calculate the pore size distribution of a given sized aggregate at any moisture level. Data obtained with this new method has shown that an aggregate often swells approximately 15 percent in volume when going from air dry to a saturated state. These data, along with results of other experiments in the Corn Belt will be useful tools in the development and evaluation of tillage specifications for various soils. (SWC 10-c2)

During the year, further evaluation of the procedures developed for securing large, undisturbed cores has been made at Temple, Texas. Cores 16 inches in diameter were successfully obtained to 6-foot depths and cores 29 inches in diameter were obtained to 9-foot depths. This procedure should be of considerable value in evaluating the importance of dense lens in heavy clay soils. (SWC 10-e1)

Work in India is continuing to evaluate the influence of organic matter on soil structure. Microphotographs of thin sections obtained from differently treated soil samples revealed that soils treated with organic matter not only had more pore space but also had a more uniform mineral grain distribution than the untreated samples. (A7-SWC-29)

At Bushland, Texas, research has shown that a generalized relation between percentage of seedlings that can emerge through a soil crust and crust strength apparently is valid for most plants in the grass family under a wide range of experimental conditions. As penetrometer values increased from 0 to about 9 bars, emergence percentage was decreased slightly. Above 10 bars emergence was drastically decreased, and above 15 to 19 bars no emergence occurred. This generalized seedling emergence soil strength relation was valid even though (1) seed size varied from that of switchgrass to that of corn, (2) oxygen concentrations varied from 7 percent to 42 percent, (3) planting depths varied from 2 centimeters to more than 10 centimeters, (4) soil moisture suctions varied from 1/3 bar to 5 bars, (5) soil temperatures varied from 70° to 95° F, and (6) gibberelic acid treatments of seeds varied from 0 to 100 ppm. (SWC 10-e1)

At Bushland, Texas, rates of cotton taproot elongation were controlled by strength of the media in which the roots were grown, even when the soil was very moist and had never been subjected to compaction by mechanical means. At 1/3-bar soil suction, roots increased their volume only 1/10 as fast in puddled as in loose soil. This change in root volume increase occurred over a wide range in oxygen concentrations. Results of these experiments have shown that soil strength affects a large number of plant growth attributes. (SWC 10-e1)

Experiments in Puerto Rico concerned with developing management systems for compact subsoils exposed by erosion have shown that exposure to heat and wetting and drying for only 2 months formed 2 inches of crumb soil structure on the surface. This weathered subsoil made a good seedbed but was extremely vulnerable to erosion during heavy rainstorms. (SWC 10-b2)

2. Tillage. A system has been developed for the humid mountain region of Puerto Rico for producing high yields of plantains on steep slopes with excellent erosion control. The system consists of planting directly in herbicide-treated sod and then maintaining a cover crop between rows. Plantains grown in this manner produced 8 tons of fruit containing 2 tons of dry matter with a caloric content similar to that of corn. In other studies, yields of tobacco, sugar cane, taniers, yams, corn, sweet potatoes, and beans on untilled soil were similar to those on tilled treatments. These findings should be of considerable value in developing tillage systems for the steep mountain slopes that are farmed in many of the under-developed countries of the world. (SWC 10-b5)

In a series of tillage studies at Morris, Minnesota, results show that the porosity of the plow-layer in plowed and plow-disk-harrow treatments was influenced greatly by the moisture content at the time of tillage. If the moisture content was below the lower plastic limit, disking and harrowing following plowing resulted in less porosity than plowing alone. However, if the moisture content was greater than the lower plastic limit, the additional disking and harrowing following plowing increased porosity. Usually the porosity of the plowed treatment was greater than the plow-disk-harrow treatment at the end of the growing season. The soil roughness of a plowed treatment was greater than the roughness from a plow-disk-harrow treatment, especially if the previous crop was a sod crop rather than corn. Frequently, the random roughness of plowed and plow-disk-harrow treatments was not different from that of untilled soil at the end of the growing season. Soil water storage during the first 5 weeks following planting was inversely related to plow-layer porosity. These data suggest that the soil moisture relations can be influenced by tillage methods. (SWC 10-c2)

The feasibility of modifying the soil surface for capturing more rainfall, increasing infiltration time, and increasing the amount of water stored was studied at State College, Mississippi. A rough soil surface created by tilling the inter-row zone of a Blackland Prairie soil to a depth of about 8 inches provided storage for about 1.5 inches of water. By the end of the growing season, the storage capacity diminished to less than 1 inch due to rainstorm sloughing. Corn grain yields were significantly increased from 100 to 111 bushels as a result of the rough surface. These findings show the potential for soil surface modification by tillage to permit maximum utilization of rainfall. (SWC 10-b3)

Results of 5 years of study on several soils in Virginia and New York indicate that if herbicides are properly used tillage is not necessary for corn production. Potato yields in Maine were the same on a single tillage treatment, involving a chisel-tooth cultivator mounted ahead of the planter, as compared to the conventional method. These studies suggest that the cost of tillage can be reduced drastically for many crops without influencing yields. (SWC 10-a1)

3. Profile modification. Observations by scientists and laymen that increased plant height and yield generally occurs immediately over trenches excavated during the installation of pipelines has aroused the curiosity of scientists. At Bushland, Texas, grain sorghum yields (both fodder and grain) were substantially increased when Pullman profiles were mixed to 5-foot depths. At equivalent fertilizer rates, the profile that was mixed yielded 8,380 pounds of grain and 10,900 pounds of fodder per acre, while the natural profile plots yielded 7,445 pounds of grain and 5,700 pounds of fodder per acre. These data indicate that soil physical conditions probably influence water use and fertilizer use efficiencies on Pullman soils. (SWC 10-e1)

At Temple, Texas, incidence of cotton root rot was decreased and lint yield was increased when Houston Black clay was rototilled to 2-foot depths. When compared to conventional tillage, the deep-tilled plots also had a greater root proliferation in the profile. However, chiseling Houston Black clay 10 inches deep on 40-inch centers did not affect root rot incidence or cotton yield. (SWC 10-e1)

In experiments conducted on Freeman silt loam near Rockford, Washington, crops of winter wheat and grass used about 1.2 inches more moisture from below the 30-inch depth where the soil was plowed 36 inches deep than where plowed only 6 inches. Wheat yields averaged 44 bushels per acre on conventionally plowed land and 65 bushels per acre on land plowed 36 inches. Grass showed similar trends, but the effects of deep plowing and fertilizers were not so striking. Optimum rates of nitrogen fertilization were 50 and 100 pounds per acre where the land was plowed 6 inches and 36 inches, respectively. On plots tilled to 48 inches with fertilizer and lime added, average alfalfa yield for the period 1962-1964 was 3.1 tons per acre as compared to 1.5 tons on plots plowed 6 inches with fertilizer and lime added. (SWC 10-f1)

On studies conducted near Pullman, Washington, wheat yields on Naff-Garfield silty clay loam were 49 bushels per acre on plots plowed 36 inches deep as compared to 41 bushels on plots plowed 6 inches deep. A marked yield response to phosphorus and nitrogen was measured at both depths of plowing. Soil moisture measurements showed that an additional inch of water was used on the deep-plowed plots. Alfalfa and grass yields were doubled as a result of deep plowing. On Palouse silt loam, wheat yielded 76 bushels per acre on land plowed 6 inches and 72 bushels when plowed 36 inches. Supporting data collected in the laboratory gave no clue as to why the Palouse soil behaved differently. (SWC 10-f1)

Results of deep plowing experiments conducted near Ontario, Oregon, and Caldwell, Idaho, suggest that sodium- and salt-affected soils in these areas are effectively reclaimed by this practice. In 1964, 8 years after the deep plowing, the chemical and physical properties of the soils indicate that a permanent improvement has been achieved. Crop yields, water intake, and water movement through the soil have all remained at satisfactory levels. (SWC 10-f1)

These data, although preliminary in many cases, indicate that considerable yield benefits can be experienced when soil profiles are modified by deep tillage. Continuation of these studies will provide needed information on the soil physical and chemical factors responsible for these yield responses.

4. Tillage pans. The influence of physical impedance on cotton root development in Coastal Plain subsoils was investigated at Auburn, Alabama.

Soil strength, as measured by a needle penetrometer and by plant growth, was affected more by moisture level than by bulk density. Percent calcium saturation was not related to soil strength. (SWC 10-b6)

Research has continued at Bushland, Texas, on Amarillo fine sandy loam to fully evaluate the relation between soil strength and the percentage of cotton taproots that penetrate soil pans. The relationship was the same for the five soil series studied. These results confirm that critical soil strength measurements, when established, will be valid for a wide range of soils. (SWC 10-e1)

Effects of soil moisture content, bulk density, and saturating cations on maximum strength of Amarillo fine sandy loam soil were also studied at Bushland, Texas. Maximum strength was developed when the soil contained 3 to 6 percent water by weight (approximately 1 monolayer of water). As the soil dried to lower moisture contents, strength decreased and then again increased as an oven-dried condition was approached. These data are in agreement with observations made by farmers that tillage pans cause the most damage in years when soil moisture is limiting. (SWC 10-e1)

5. Mulches. Three tons of straw per acre applied as a mulch on tobacco effectively controlled soil crusting of exposed subsoils in Virginia. The additional moisture stored on the mulched plots was reflected in increased green and cured leaf yields. (SWC 10-a1)

Woodchips applied at a rate of 7 tons per acre as a topdressing markedly increased aggregate stability and soil moisture in a vegetable cropping system at Marcellus, New York. Cabbage yields under the mulch averaged 24.7 tons per acre as compared with 18.4 tons on unmulched plots. The yield increases were attributed to the moisture conserved by the woodchip topdressing during a rainfall deficient-growing season. (SWC 10-a1)

Although the economical benefits of the above two studies have not been fully evaluated, it would appear that these practices are feasible.

Mulches continue to markedly increase soil temperature in field experiments at Prosser, Washington. Sweet corn planted in mid-April and covered immediately with asphalt spray emerged earlier and, consequently, was harvested 5 days earlier than corn planted at the same time on plots without mulch. (SWC 10-f1)

At Sidney, Montana, in a season of near-normal rainfall, winter wheat yields were significantly higher under 3,000 pounds per acre of surface residue. The 3-bushel per acre yield increase was attributed to increased moisture content of the top 3 inches under the mulch. Overall development of winter wheat was not appreciably affected at Bozeman, Montana, by varying rates of residue application following summer fallow. At Akron, Colorado, during a normal rainfall season in a wheat-fallow system,

6,000 pounds per acre residue resulted in an additional inch of stored moisture, which was reflected in a 3-bushel per acre yield increase. At North Platte, Nebraska, during a cool, wet growing season, winter wheat yields were as much as 13 bushels per acre lower when 3,000 pounds straw per acre was left on the surface as compared with fall incorporation of the straw. Decreased production on surface-mulched plots was due to smaller number of heads per square foot. Soil temperatures at the 3-inch depth were lower under the residues all during the growing season. These data are in agreement with previous findings that decreased yields from straw mulches are greater during a cool, wet growing season. The factors responsible for these decreased yields will receive further study. (SWC 10-d5)

6. Cropping systems. Long-term studies were continued at Watkinsville, Georgia, to develop efficient soil and water conservation practices for the Southern Piedmont. Results from the 10-year study show that corn yields following alfalfa, Coastal bermudagrass, and fescue sod were significantly higher than continuous corn yields at nitrogen levels ranging from 0 to 160 pounds per acre. Corn in the sod-based cropping systems made more efficient use of the available soil water and applied nitrogen than continuous corn. An incubated nitrate-nitrogen soil test correlated with soil nitrogen values from differently cropped soils. (SWC 10-b4)

Studies also continued at Fleming, Georgia, in an attempt to develop a vegetable-grass cropping system for the Coastal Plain soils. Tomatoes, okra, squash, and southern peas gave higher yields when planted in Coastal bermudagrass than on continuously cultivated land. Grass in a 2-year grass and a 3-year corn rotation at Florence, South Carolina, decreased meadow nematode infestations and increased corn yields. The beneficial effects of grass persisted through three successive years of corn. (SWC 10-b4)

Corn production on various land slopes is being evaluated at 9 locations in Georgia and South Carolina. Corn yields on the 10 percent slope were slightly lower than on the 5 percent at 4 locations; but at 2 locations, yields were higher on the 10 percent slope. These results indicate that corn yields on steep slopes can be expected to be as high as on the lesser slopes, providing the corn is planted on the contour. Intensive management systems developed for the major grasses of Puerto Rico have resulted in the consistent production of over 1,000 pounds of beef per acre yearly for the past 5 years on steep slopes. These grasses provided excellent erosion control. Results show one efficient way of using steep mountain lands intensively while conserving the soil. (SWC 10-b4)

In the Imperial Valley of California, cropping systems that include alfalfa or manure continue to produce higher sugar beet yields regardless of fertilizer application. With all rotations, better sugar production was obtained where all crop residues were returned to the soil instead of

removing them. Additional information on the physical or chemical properties of these soils will be necessary to identify the primary factors responsible for the yield increases due to alfalfa, manure applications, and residue management. (SWC 10-g1)

D. Soil Microbiology

1. Decomposition of residues. Research is continuing at Beltsville to isolate the mechanisms responsible for the rapid increase in the rate of mineralization of nitrogen when a soil is moistened after being dry for a prolonged period. Increased temperature and exposure to light accelerated the mineralization process, but the presence or absence of atmospheric oxygen did not have a noticeable influence. (SWC 10-aB3)

Reduced yields under stubble mulch farming systems in the Great Plains have resulted in limited acceptance of this soil erosion control practice. In studies at Lincoln, Nebraska, concerned with isolating phytoxic substances, extraction methods have been developed, a purification procedure perfected, and a two-dimensional paper chromatography separation devised for determining patulin in soil. These analytical techniques will permit study of the cultural conditions affecting patulin production in soil. (SWC 10-d5)

Studies on antibiotic production in soils at Beltsville have furnished further direct evidence that antibiotic production is associated with the decomposition of plant residues in the soil. Aureomycin and terramycin production reached highest concentrations 5 days after soybean and alfalfa residues were added to sterile soils and then fell as the decomposition subsided. (SWC 10-aB3)

2. Inoculation of legumes. Inoculation of legumes with introduced strains of Rhizobium is frequently only partially successful because of competition with the Rhizobium already present in the soil. Studies at Beltsville, using a serological method of identifying Rhizobium strains in soybeans, showed that seed inoculum produced very few nodules in competition with rhizobia already in the soil. Evidence was obtained that introduced strains differed greatly in their competitive nodulating ability. (SWC 10-aB6)

In spite of considerable work done in the past on the taxonomy of the genus Rhizobium, it is still not known whether rhizobia from widely different host species are closely or only distantly related. Studies have been initiated at Beltsville to study genetic relatedness among Rhizobium strains. The project is still in the preliminary stage of standardizing equipment and procedures. (SWC 10-aB6)

In continuing research at Beltsville on the chlorosis toxin produced by certain soybean rhizobia, improved isolation and purification procedures

were developed which made it possible to collect sufficient quantities of pure toxin for identification and biological activity studies. Results showed that less pure toxin than the amount produced in a single nodule will induce chlorosis in susceptible soybean plants and that over four times as much toxin is needed to induce chlorosis in resistant varieties as in susceptible varieties. Further investigations are being directed to chemical identification of the toxin. When this is accomplished, it will be possible for the first time to isolate the biochemical mechanism of host resistance. (SWC 10-aB6)

During the year fundamental studies conducted in a PL 480 project in Poland on the genetics and variability of Rhizobium was completed. In these studies, gamma radiation changed the chemical composition of the Rhizobium cells. Nutritional investigation showed that a close relationship exists between certain strains of Rhizobium. Information on the symbiotic nitrogen-fixing power of Rhizobium strains was not conclusive. (E21-SWC-3)

In a continuing study in India to evaluate the contribution that soil algae makes to the fertility of rice fields, results show that five algae species fix nitrogen. The data indicate that the presence of bacteria with the algae leads to more nitrogen fixation. Because the data were irregular, the experiments will be repeated in the field during the coming season. (A7-SWC-7)

3. Plant diseases. Many of the disease organisms that affect plants exist in the soil environment. Studies at Beltsville have shown that the resting structures of the Verticillium wilt fungus will germinate in soil in the absence of the host plant and will build up a temporary high population of the pathogen. This increased population appears to consist mostly of delicate spores that quickly die in the soil. The resting schlerotia are weakened by this germination process and become progressively sensitive to desiccation. The multiplication is affected by soil moisture, energy supply, and other factors that influence activity of the total microflora. These findings suggest that control of some plant diseases should be possible by the development of tillage and other soil management practices.

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AREA 11: SOIL, WATER, AND PLANT RELATIONS AS THEY AFFECT USE OF LAND AND WATER RESOURCES

Problem. Most of the water used in this country is returned to the atmosphere by the process of root absorption and transpiration. Our understanding of the physical, physiological and phenological aspects of the extraction of water from soil by roots, its condensation upward and the manner in which water is lost from the leaves is limited. The productiveness of the soil depends to a large degree on how water moves within the soil. The mechanisms involved in the movement of water in the soil and to the plant root have not been adequately explained; consequently, a satisfactory prediction of the behavior of water in soil cannot be made. No basic understanding of naturally occurring field phenomena can be reached until our knowledge of water movement through soils and to plant roots is understood.

The immediate climatic environment around the plant and at the soil surface and the micrometeorological factors which affect these have a profound influence on the growth of the plant, the loss of moisture from the soil and plant and upon the soil itself. These micrometeorological factors offer a means of conserving moisture during the course of plant development. It has been estimated that 80 percent of the sun's energy is used each year to evaporate some 2 million acre-feet of water from plants and soil. The total energy cannot be altered, but it should be possible to divert a greater percentage to use for photosynthesis rather than evaporation.

USDA AND COOPERATIVE PROGRAM

The Division program in this area involves soil physicists, soil chemists, plant physiologists, and engineers in both basic and applied studies. The Division scientific effort devoted to this research totals 27 professional man-years. Of this number, 12.5 are devoted to relation of the physical properties of the soil on the movement of water to and into plant roots; 10.5 to determination of plant-soil-meteorological interactions; and 4.0 to development of soil and crop management factors for maximum energy conversion.

PROGRAM OF STATE EXPERIMENT STATIONS

Many of the State stations are conducting basic and applied investigations on soil-water-plant relationships. These studies involve agricultural

engineers, agronomists, horticulturists, plant physiologists, soil chemists and soil physicists. Frequently a team representing different disciplines work together on individual projects.

In the Northeastern region, 9 stations are contributing to regional project NE-48, Soil-Plant-Water Relationships, whose objectives are to study the energy status and dynamics of water in soils and plants, to determine the influence of plant and environmental parameters upon water extraction from the soil profile and to relate physiological conditions in plants to water stress. Investigations are being conducted on the energy required for the movement of water into and through tomato plants subjected to different environmental conditions, effect of high stress on ability of a plant to conduct water, water requirements of asparagus and the ability of the plant to take up water during the cutting season, the extent of transfer of water from one portion of a root system to another where the difference in free energy of the soil water for the two portions of the root system is great, the contribution of water from underlying or surrounding layers to the root zone, and the relation between root attributes of selected forage crops and their capacity to extract water from soil profiles.

In the Western region, 8 states and the USDA are cooperating on regional project W-67, Water-Soil-Plant Relations. The objectives of this fundamental project are: (1) to investigate relationships between water stress in root medium and internal water status of plants as affected by environment and plant development; (2) to evaluate effect of plant structures, physiological processes and transpiration retardants on water movement and loss from plants; (3) to determine effects of plant water stress and nutrients on morphology and metabolic processes determining growth and composition of plants; and (4) to seek unification of divergent hypotheses concerning soil water and its effects on plants as a basis for developing concepts leading to more efficient use of water.

Research also is in progress to determine the morphological and physiological responses of trees to soil moisture variables both for newly planted and producing citrus trees, the effects of soil moisture availability on seed germination and seedling development, the differential response of winter wheat varieties to soil moisture stress and nitrogen availability, the physiological defects of potato tubers as related to moisture availability and root temperatures, the physiological significance of internal water status of plants as measured with beta ray gauging, the use of stomata-closing chemicals to retard transpiration, and the nutritional requirements of cotton under different moisture regimes on selected soils of the Trans-Pecos area.

The total State research effort in this problem area is 55 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. The Relation of the Physical Properties of the Soil on the Movement of Water To and Into Plant Roots

1. Redistribution of water in the soil profile after irrigation. With the increased concern about water shortages in the West, the development of irrigation practices that will provide for maximum efficiency of water use and adequate leaching of salts remains as the biggest challenge that faces agricultural scientists in that area. In order to meet this challenge, it is imperative that the amount of downward movement of water after irrigation or rainfall can be estimated from simple measurements. At Riverside, California, field plots planted to alfalfa, birdsfoot trefoil, and bermudagrass have been instrumented with tensiometers at 50-cm. intervals to a depth of 200 cm. and with neutron meter access tubes. During the past year, data have been collected on the pattern of water movement through the root zone as a function of frequency and quantity of irrigation water applied. A preliminary analysis of the data indicates that it should be possible to estimate the soil water diffusivity in the field for some water content values and that a simple mathematical equation may be used to describe water content changes in relatively homogeneous soil profiles below about 50-cm. depth. Data have been collected also from 270-cm.-long soil columns in the laboratory so that by comparison with the field data, a better estimate of the role of plant roots in determining the water content pattern can be obtained. In both the laboratory and the field, a long period of data collection will be required before an adequate analysis can be attempted. (SWC 11-gF1)

2. Movement of water in and from the soil reservoir. A basic description of the physical and chemical processes involved in the removal of moisture from the soil reservoir has never been developed. Temperature differences in the soil cause moisture to move from warm to cool areas in both the liquid and vapor phases. At Davis, California, experiments were conducted to define the relative importance of temperature difference and to examine the mechanisms of moisture transfer. Simultaneous flows of heat and moisture were measured under various temperature and pressure gradients in a manner that the liquid and vapor flow components could be separated and the liquid component could further be divided into that flowing due to pressure differences and that due to thermal differences. It was found that a temperature gradient of 0.5°C/cm. at a low soil moisture suction (5 cm. of Hg) would move as much water through the soil as a pressure gradient of 2 cm. of water per cm. At a higher suction, this temperature gradient was equivalent to a pressure gradient of 250 cm. of water per cm. Vapor transport through the soil was several times greater than could be predicted with Fick's law and the diffusion of water vapor in air. A linear thermodynamic moisture flux equation was developed in terms of commonly used flow coefficients and variables to predict fluxes in agreement with experimental observations. These data are of value in explaining the moisture accretion at

the frozen soil zone that has been reported by several investigators. (SWC 11-13g1)

3. Infiltration and movement of water in dry soil. Water moves in both the liquid and vapor states during infiltration into air-dry soils and the temperature increases when water vapor is adsorbed by the soil. At Brawley, California, infiltration into air-dry soil was performed with thermistors spaced at 5-cm. intervals to observe the temperature change attributable to the adsorption of water vapor ahead of the liquid front. The vapor front was shown to move faster than the liquid front, but they both moved as a linear function of the square root of time. It was shown that the isothermal flow of water during infiltration occurs only at some distance behind the liquid front in the wetter portion of the soil. (SWC 11-13g1)

4. Effect of salts on water movement. Osmotic changes brought about by changes in salt concentrations of the soil solution have been experimentally shown to alter the movement of water in soils. The rate at which a soil dries could also be influenced by the accumulation of salt near the soil surface. An experiment to study the effect of salt on the vapor pressure of soil moisture was conducted at Davis, California. A method developed to measure the vapor pressure of a moist surface during steady state evaporation was used to measure relative humidity of a loam soil over a range of evaporation rates. The data were interpreted in terms of the degree of salt accumulation in the air-water interface. Even at low evaporation rates, salts in the soil solution accumulated at the air-water interface and reduced the vapor pressure. At evaporation rates of less than 1 mm. per day, the concentration of salts at the air-water interface was twice that of the soil solution. Concentration often rose to more than 4 times that of the bulk solution at evaporation rates of less than 0.5 mm. per day. The concentration at the interface was dependent on the mobility of salt in solution, the evaporation rate, and temperature. The importance of interface accumulation of salts as related to the evaporation of water from leaves and the transport of solutes across semipermeable membranes warrants further study. (SWC 11-13g1)

The movement of water adjacent to mineral surfaces is an important factor in ion exchange and all phenomena involving the movement of water or ions through soil. At Fort Collins, Colorado, a study was designed to determine the mobility of water adjacent to sodium- and calcium-saturated bentonite surfaces. Results showed that the first molecular layer of adsorbed water on sodium and calcium clays had mobilities that were 30 and 5 percent, respectively, of the mobility of water molecules in bulk water. However, with both ions, water more than three molecular layers from the solid surface had mobilities which were 60 percent that of bulk water. These data suggest that salt gradients in soil-water films can be just as important as hydraulic gradients. (SWC 11-d1)

All soil waters contain a small amount of dissolved silicate. The deposition of cementing silicates as a result of evaporation or changes in chemical environment as the water percolates through the soil can cause cementation, which influences the geometry of the pore spaces and, hence, alters the permeability of the soil. In a study at Fort Collins, Colorado, to evaluate the importance of silicates in forming aggregates and hard layers, results showed that silica does precipitate at points of contact between sand grains during drying. The deposited silica cements the sand grains into hard aggregates. Further study will be directed to the development of methods that will control or eliminate these cemented layers. (SWC 11-d1)

Water flow problems of interest to agriculture can best be solved by the use of computers. Before computers can be used with confidence on broad water problems, a check on the numerical solutions must be made with small models. In a continuing study at Urbana, Illinois, the solutions of water flow problems of major interest are being obtained by the development of a computer program that computes the water content and diffusivity from laboratory results. The data show that interpretation of the effect of soil management treatments cannot be made from diffusivity function alone. A simultaneous measurement of the water capacity function is necessary. Future studies will involve checking the predictions made on water flow through a given soil by the mathematical solution. (SWC 11-c3)

Hydraulic conductivity under field conditions is most difficult to measure on soils that shrink when dried and swell when wetted. Laboratory studies made on 3-inch undisturbed cores taken from various horizons of Houston Black clay showed that the bulk density increased with depth, but the permeability decreased with depth. The bulk density of saturated samples was less than at field capacity because swelling increased the soil volume. These data give some insight on the limitations of the common laboratory methods used to determine the effects of physical problems on the movement of water through the soil. Future work will be done with large cores (30 inches in diameter and 6 feet long) in an attempt to get volumes large enough that swelling will not influence permeability rates. (SWC 11-e1)

The development of the neutron moisture probe has made it possible to more carefully follow soil moisture movement in laboratory and field studies. However, the question of how to properly calibrate the instrument remains unanswered. At Brawley, California, a comparison between field calibration of neutron moisture probes and laboratory calibration in 3-foot-diameter barrels, suggests that laboratory calibrations should not be used to interpret field data. Evidently, the laboratory calibration in barrels containing disturbed soil does not represent field conditions. When the soil in barrels is wetted, the dry bulk density declines while the moisture content on a volume basis increases. The soil in the barrel tends to be fluffy, which allows the path length of the fast neutrons to become

large, thereby reducing the number of thermal neutrons returning to the vicinity of the detector below that normally occurring in the field at the same moisture content. (SWC 11-13g1)

5. Water movement in roots. While a great deal of effort has been directed to the rate at which water moves into and through soils, the factors governing the entry of water into roots has received little attention. If the information on water movement in soils is to be intelligently utilized, basic information on the manner in which a plant regulates its water economy must be available. In a continuing study at Urbana, Illinois, on the physical factors governing water movement into and through plants, progress to date indicates that most water movement in plant roots involves the protoplasm. Normal roots were fairly uniform in their resistance to water movement, but water movement in roots treated with an inhibitor was confined to the cell wall. The diffusion coefficient in the root was a substantial fraction of the coefficient in free water. While the above data are far from being complete, they do represent progress in attaining knowledge on this phenomena. (SWC 11-c1)

B. Determination of Plant-Soil-Meteorological Interactions

1. Radiant energy absorption in soybeans and cotton. In the last decade, corn yields have increased 50 percent in the Corn Belt, while soybean yields over the same period have stayed about the same. An experiment, initiated in 1964 at Urbana, Illinois, to study the influence of light, water, and carbon dioxide on soybean production, showed that 9 inches of water applied to soybeans in 20-inch rows increased yields from 43 to 57 bushels per acre. Leaf area index was not related to grain yield. Net radiation measurements indicated that plant movement caused by wind increased substantially the amount of photosynthetic radiation which penetrated the crop canopy. New techniques are being developed to more fully evaluate this phenomenon and to assess its value in enhancing the radiation process. (SWC 11-c2)

In studies at State College, Mississippi, on the relationship of cotton growth to microclimate, north-south rows daily intercepted 22 percent more light than east-west rows. The influence of row orientation on light interception was much greater in skip-row cotton than in solid planted rows. In all cotton stands, net photosynthesis during the day paralleled very closely the amount of light intercepted. These findings suggest that row direction could have an appreciable influence on crop yield. (SWC 11-b1)

Studies are continuing at Ithaca, New York, to evaluate the energy budget in various crops. Results show that the upper 20 percent of a corn crop accounts for 50 to 90 percent of the total fixation of carbon dioxide, depending on the time of day. In this study, the amount of carbon dioxide

used increased as the speed of the wind increased. Further studies of the exchange of carbon dioxide and water vapor in the crop canopy as influenced by wind speed revealed that during the daylight hours, the transfer coefficients for heat and water vapor are greater than the transfer coefficient for wind. This means that the "free convection" process due to heating of the air in the crop canopy enhances the exchange of gases, such as carbon dioxide and water vapor. (SWC 11-a1)

2. Stomatal activity. The many factors which influence the stomatal opening and closing in leaves are not understood. In growth chamber studies at Watkinsville, Georgia, increasing the carbon dioxide concentration of air reduced the transpiration rate of corn and sorghum plants and, to a lesser extent, of cotton, soybeans, and tomato plants by causing the stomata to close. Closure of corn and sorghum stomata occurred at 2,000 ppm. and 3,000 ppm. of carbon dioxide, respectively. Complete closure of cotton, soybean, and tomato stomata did not occur at concentrations up to 4,000 ppm. A technique was developed which allowed for a precise analysis of cellular changes associated with guard cell action. Isolated stomata have been opened and closed, reversibly, by changing pH, osmotic potential, and carbon dioxide concentration of the liquid media. These findings indicate that the carbon dioxide must be monitored in controlled moisture studies involving plants if the data are to be properly interpretated. (SWC 11-b2)

Previous findings at the U. S. Water Conservation Laboratory, Tempe, Arizona, showed that the leaf water content oscillated many times during the day, indicating that there were corresponding variations in the stomatal aperture. New studies, directed to evaluate this phenomenon, recorded cyclic changes in stomatal aperture and concurrent changes in transpiration (from weighing plants), leaf temperature (from microthermocouples), and leaf water content (from beta ray gauge) of cotton plants under carefully controlled growth chamber conditions. Though as yet unexplained, these data indicate the existence of a feedback control mechanism in plants whereby water absorption by the roots is regulated by the water balance of the plant to match evaporation from the leaves. (SWC 11-gG1)

The effect of light intensity upon stomatal activity was investigated in the field with irrigated cotton and in the climate room with five different plant species at Tempe, Arizona. The data obtained indicate that the light intensity must be at least 4,000 to 5,000 foot-candles before stomates are fully opened. Significant differences with regard to the light effect were found between species and between upper and lower leaf surfaces. In addition, field studies with cotton demonstrated that only after drastic soil moisture depletion would stomatal closure take place. (SWC 11-gG1)

In well-instrumented field studies at Ithaca, New York, concerned with water relations in the plant, carbon dioxide concentrations in the stomatal guard cells and the turgor relationships of cells adjacent to

stomatal guard cells appear to be the two mechanisms that control stomatal openings in leaves. These data suggest that soil moisture, evaporation rate, and windspeed are the factors that control transpiration and photosynthesis under field conditions. Data collected on these experiments provide some important guides for the development of soil and crop management systems that will make for the efficient use of water. (SWC 11-a1)

3. Influence of soil temperature on plant growth. At Orono, Maine, a detailed greenhouse study was made of the influence of soil temperature on potato growth and development. When seed pieces were planted at 48° F., no emergence occurred even after 60 days. However, if the seed was germinated at 60° F., root growth was as good at 48° F. as at higher temperatures. Top growth increased with increasing temperature, up to and including 84° F. but tuber yield was greatest at 72° F. and lowest at 84° F. Tuber initiation was greatest at 48° F., but tuber development was retarded at this temperature. These data are of great value in developing management systems for this important potato-producing area. (SWC 10-a1)

Studies of management systems designed to control soil temperature have continued at Temple, Texas. Early season soil temperature had to be increased 4° to 8° F. before the growing season for grain sorghum was shortened and grain yields increased. During the grain forming period, a 6° F. (80 to 74° F.) decrease in soil caused grain sorghum yields to be reduced, but did not influence corn yields. (SWC 11-e1)

C. Soil and Crop Management Factors for Maximum Energy Conversion

1. Timing of irrigation water. The search for meaningful measurements for scheduling the application of irrigation water continues at Weslaco, Texas. Results to date show that the moisture suction on the surface 2 feet of soil, the average plant temperature at the crop's height between 1:00 and 3:00 p.m. of the sampling day, and the solar radiation from 2:00 to 2:30 p.m. are the most reliable measurements. These findings indicate that there is no carryover effect of previous stress conditions on the relative turgidity measurement and that a single equation can be used to represent all irrigation treatments exposed to the same meteorological conditions. (SWC 11-e1)

In areas concerned with producing vegetables for the winter market, the question of what irrigation schedules are required for maintaining the maximum soil temperature below that which is damaging to seedlings established in July and August has never been satisfactorily answered. An evaluation of net radiation (difference between incoming and outgoing radiation, or amount absorbed at soil surface) over irrigated and non-irrigated plots at Weslaco, Texas, revealed that there was a rise in net radiation following irrigation which lasted for 3 or 4 days corresponding in time to the appearance of surface drying. There was also a sharp

decrease in soil temperature for 5 to 8 days following irrigation brought about by evaporation. In the nonirrigated plots, the temperature at the soil surface was as high as 75° C., which exceeds the thermal death temperature of protoplasm. These data suggest that irrigations at 5-day intervals are required for establishing seedlings in July and August in the Lower Rio Grande Valley. (SWC 11-e1)

The practice of continuously irrigating sugar beet and lettuce seed beds to reduce soil temperature in the Imperial Valley has been questioned by scientists at Brawley, California. Experimental results revealed that beds irrigated continuously had the same soil temperature at the 1-inch depth as those beds irrigated every 5 days. This information indicates that continuous irrigation of row crops during germination in July and August is not necessary for reducing soil temperature, but only wastes irrigation water that is already in short supply. (SWC 11-g1)

At Morris, Minnesota, the evaluation of the extent to which microclimate can be controlled or modified by small temporary windbreaks has continued. The 1964 results showed that corn rows spaced 40 feet apart and across the prevailing wind increased soybean yields 4 bushels per acre as compared to unprotected areas. Water use efficiency (pounds of grain produced per inch of water used in evapotranspiration) was also increased by sheltering with windbreaks. All micrometeorology measurements taken in the experiment indicated that the barriers beneficially altered the microclimate in the soybeans. This simple inexpensive management practice should receive wide application in agricultural areas concerned with limited water supplies. (SWC 11-c2)

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AREA 12: NUTRITION OF ANIMALS AS AFFECTED BY PROPERTIES AND CHARACTERISTICS OF SOILS AND PLANTS

Problem. To improve nutrition of animals and man by discovering relationships among soils, plants, and animals; to develop basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals; to determine the functions and pathways of transport of the various elements throughout the food chain from soil to plant to animal; to identify and characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by qualities of the plants produced; to determine the relationships among soil properties, both natural and as modified by treatment, climatic factors, and the nutritional quality of plants as measured chemically or by feeding test animals, so as to enable farmers to select economic combinations of soil, crop, and livestock management practices that will meet human nutrition needs.

USDA AND COOPERATIVE PROGRAM

This research is centered at the U. S. Plant, Soil, and Nutrition Laboratory, a U.S.D.A. Laboratory, located on the campus of Cornell University. Problems in animal nutrition that are prevalent in specific regions are investigated through field surveys in which the incidence of the nutritional problem is related to the composition of forages, types of soil, and other environmental factors. Recent work of this type includes studies of the relationship of selenium in forages to the incidence of muscular dystrophy in livestock. The chemistry of micronutrients in soils is under intensive study in order to develop basic knowledge of factors that influence the micronutrient content of plants. Other investigations are directed toward understanding the functioning of micronutrients in the animal, and the mechanisms involved in the interactions between micronutrients in animal nutrition. Studies of the site and mechanism of absorption of trace elements in the gastro-intestinal tract are under way. The processes involved in the synthesis and breakdown of nutritionally important compounds in plants and animals are under investigation. One phase of these studies is directed toward the mechanism of formation and metabolism of amino acids and related compounds in plants, with special attention being directed toward the sulfur-containing amino acids. Another phase of this work is concerned with the mechanisms whereby amino acids are linked together to form protein, and the relationship between molecular structure and the biological function of some of the compounds that play important roles in protein synthesis. During the past year, the first determination of the structure of a ribonucleic acid was accomplished as part of this work.

Studies involving large animals are conducted through cooperation with State agricultural experiment stations. An investigation of the effect of soil applications of selenium upon the incidence of myopathy in sheep is being conducted at Oregon State University.

The Federal scientific effort devoted to research in this area totals 18 professional man-years. Of this number, 3 are working to characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by quality of plants produced; 3 are devoted to basic understanding of the metabolism of nutritionally important elements in animals; 4 to assays of plant material grown under different soil, geological, and other environmental conditions in relation to nutritional disorders in animals and man; and 8 to elaboration by plants of vitamins, amino acids, proteins, and other organic nutrient compounds required by animals. The Soil Conservation Service maintains a full-time scientist at the Plant, Soil, and Nutrition Laboratory for studies relating nutritional problems to specific kinds of soil.

PROGRAM OF STATE EXPERIMENT STATIONS

Soil and climatic factors which influence plant composition so that livestock which feed upon these plants develop toxic, deficiency or unthrifty conditions are being characterized. The problems are sometime mineral deficiencies such as cobalt, copper, selenium, and iodine; sometimes it is an excess such as molybdenum or selenium and sometimes the production of toxic levels of such factors as oxalates and hydrocyanic acid. Proper supplementation to overcome the deficiencies and management to prevent damage from the excesses are being investigated.

Studies are being made to develop an understanding of the fundamental soil factors influencing the synthesis of nutritionally important substances such as vitamins, proteins, carbohydrates and other nutrients and the plant content of nutritionally important minerals.

Nutrient deficiencies or excesses in feeds are being identified through the development of biological assay methods for the rapid determination of such nutrient deficiencies or excesses. These methods will provide needed information to identify the soil, geological and other factors which contribute to nutritional disorders of man and animals.

The total State agricultural experiment station effort in this problem area is 20* professional man-years.

*Also reported in Animal Husbandry.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Biosynthesis of Amino Acids, Peptides, and Proteins

1. The structure of an alanine transfer RNA. It has been suggested that micronutrients influence plant growth predominantly in protein synthesis. The problem has been that our knowledge of the chemical processes involved in protein synthesis is not understood. A step towards understanding how plant and animal cells manufacture protein was completed during the year at the U. S. Plant, Soil, and Nutrition Laboratory, at Ithaca, New York. This is the first time that the structure of a ribonucleic acid (RNA)--or any nucleic acid--has been determined. Ultimately this research may lead to ways of altering genetic characteristics of living organisms by modifying the structure of nucleic acids. Nucleic acids also have a role in cancer growth and virus-disease transmission. The alanine transfer RNA, one of the smallest biologically active nucleic acids known, carries activated amino acids to the site of protein synthesis. During protein synthesis, the amino acid sequence of the polypeptide chain is determined by the interaction of a messenger RNA with amino acid-specific transfer RNA's. (SWC 12-aA4)

At the time this work was undertaken, it was commonly assumed that it would not be possible with ordinary fraction techniques to separate an individual nucleic acid from the complex mixture in which the transfer RNA's appeared. The group at the laboratory, however, using the counter-current distribution technique, was able to obtain three pure RNA's, specific for alanine, tyrosine, and valine. Studies of the compositions of pancreatic ribonuclease digests established that the three RNA's have quite different structures, as indicated by oligonucleotide sequences. A number of oligonucleotides obtained from the three RNA's have been identified. (SWC 12-aA4)

Determination of the structure of the alanine RNA involved the identification of small fragments formed by complete digestion of the RNA with pancreatic ribonuclease and takadiastase ribonuclease T1, followed by the determination of the structures of successively larger fragments, until the complete sequence of the RNA was established. (SWC 12-aA4)

In the course of the structural work, new methods were worked out for the purification of the snake venom phosphodiesterase and its use in establishing the sequences of oligonucleotides. An unusual base, dihydrouridylic acid, was identified in the alanine RNA and its presence detected in several other RNA's. This was the first report of the presence of a dihydropyrimidine in a nucleic acid. An unusual tetranucleotide sequence present in the alanine RNA was similarly detected in many other RNA's. The finding of common structural features in the transfer RNA's is of particular interest as a clue to the functional significance of various parts of the

structure. In this connection, the work now in progress on two tyrosine RNA's should prove very valuable. This knowledge is of great value in evaluating the possibility of controlling soil micronutrient deficiencies and toxicities. (SWC 12-aA4)

2. Nitrogen and sulfur compounds of plants. Increases in total nitrogen or crude protein in plants through intensive fertilizer practices do not necessarily result in an increase in protein of high nutritional quality. Soil mineral elements, such as selenium, can substitute for sulfur in certain amino acids resulting in a poor quality protein. An understanding of the mechanism involved would make it possible to develop a balanced fertilizer program to assure the production of quality feeds. (SWC 12-aA7)

Studies to evaluate the influence nutritional quality of plants has on the sulfur amino acids content has continued. One of the sulfur compounds of plants is S-methylcysteine, which is closely related to methionine and cysteine, the sulfur amino acids which are so important nutritionally. Studies on the metabolism of radioactive compounds in detached leaves have shown that both cysteine and the methyl group of methioine are involved in the formation of S-methylcysteine. Further work has indicated that methioine is converted to S-adenosylmethionine or methylmethionine before transferring its methyl group to cysteine. Studies have been initiated to demonstrate these reactions in cell-free systems. In cell-free systems, it has been possible to synthesize methionine and an amino acid that has properties similar to that of S-methylcysteine. (SWC 12-aA7)

Studies have been made on the formation and metabolism of cysteine in plants. Cell-free preparations of plant tissue have been found to degrade cysteine rapidly. Apparently, this is a partial explanation for the low level of nonprotein cysteine in plants. This may provide an important key to some control over the levels of all sulfur amino acids in plants. (SWC 12-aA7)

In kidney beans, such S-methylcysteine occurs as a γ-glutamyl dipeptide. Work from the laboratory had previously shown that this dipeptide is formed by enzymatic transfer of a glutamyl group from gluthathione to methylcysteine. It has been found that this enzyme from kidney beans can hydrolyze glutathione at physiological pH's without transferring a glutamyl group to an amino acid. This suggests that the normal function of the enzyme in the plant may be to hydrolyze γ-glutamyl peptides, but that under certain conditions, it also synthesizes dipeptides. (SWC 12-aA7)

Last year, it was reported that evidence had been obtained that m-carboxyphenylalanine is converted to m-carboxyphenylglycine in plants. Since then, it has been conclusively shown that the alpha carbon of the m-carboxyphenylalanine becomes the carboxyl group of m-carboxyphenylglycine.

This is significant because (1) it makes it possible to suggest pathways for the interconversion, and (2) this type of interconversion has not been heretofore shown between homologous amino acids. (SWC 12-aA7)

Studies on urea metabolism have been continued during the year. Urea or ammonia labeled with isotopic nitrogen has been fed to plants and the nonprotein amino acids separated and analyzed for isotopic nitrogen. These results have shown that urea is not metabolized like ammonia. However, it was not possible to deduce the precise pathways involved in urea utilization. In other experiments with C^{14}-labeled urea, it has been shown that carbon dioxide is an early product of urea metabolism and that carbamyl phosphate is not formed from urea. This information is of value in developing fertilizer practices that will make for the production of feeds of high nutritional quality. (SWC 12-aA7)

B. Trace Element Functions and Interactions in Animal Nutrition

1. The site of assimilation of trace elements in the gastrointestinal tract. In order to understand the influence of soil micronutrients on livestock diseases, it is necessary to gain some insights on the biochemical functions of the mineral nutrients on bone formation and physiological functions of the animal. Work aimed at determining sites of and mechanisms for the absorption of micronutrients from the intestinal tract has been continued. One area of investigation dealt with the absorption of several radioactive ions from isolated segments of the gastrointestinal tract. The isotopes tested were Cu^{64}, Zn^{65}, Fe^{59}, and Mo^{99}. Zinc, iron, and molybdenum were tested because they have all been shown, at various times and places, to be involved with the utilization of copper. The absorption of these elements was tested by placing them, individually, in ligated, *in vivo* segments of rat gastrointestinal tract. The four segments tested were: stomach, duodenum, a section in about the middle of the small intestine, and the terminal segment of the small intestine. Cu^{64} was absorbed most rapidly from the stomach, and the tissue uptake of this isotope declined as the Cu^{64} was placed in segments located further down the intestinal tract. In contrast to the behavior of copper, Zn^{65}, Fe^{59}, and Mo^{99} displayed absorption patterns in which absorption was highest from the duodenal segment and lowest from the stomach for all three of these isotopes. The quantitative aspects of absorption of these isotopes from the various sites reveal some large differences that can be illustrated amply by comparing uptake of a given isotope from the duodenum to uptake of the same isotope from the stomach. These duodenum/stomach ratios were as follows: Cu, 0.7; Zn, 112.6; Mo, 2.6; and Fe, 8.5. (SWC 12-aA3c)

The observation that Cu^{64} was absorbed most rapidly from the stomach, while Zn^{65} was absorbed fastest from the duodenum, and the knowledge that Zn can act as a Cu antagonist, led to some speculation on fundamental differences in absorption from the two sites. The only aspect of this

question which has been tested thus far is whether Zn affects the absorption for Cu^{64} from the stomach and from the duodenum in the same manner. It was found that Zn at lower levels (Zn/Cu equal to 50) slightly stimulated Cu^{64} uptake from both the stomach and the duodenum, but that Zn at a somewhat higher level (Zn/Cu equal to 500) significantly inhibited uptake of Cu^{64} from either site. It was concluded that Zn affected Cu^{64} uptake from the stomach and from the duodenum in the same manner and to about the same extent. (SWC 12-aA3c)

This influence of Zn on Cu^{64} uptake from ligated segments stimulated interest in other cations known to affect overall Cu utilization. Along with Zn, Cd, Ag, and Hg were tested for their effects on the absorption and distribution of Cu^{64} in rats. These effects can be summarized as follows: Zinc depressed absorption but did not affect the distribution of Cu^{64} uptake and at high levels, increased the relative proportion of the absorbed Cu^{64} found in the blood, heart, and spleen, and reduced the proportion found in the liver. Silver had little effect on absorption, but caused an increased deposition of Cu^{64} in the liver and a reduced Cu^{64} content in the blood. Mercury also had a minor effect on absorption, but caused a marked increase in the deposition of Cu^{64} in the kidney and a corresponding decrease in the isotope content of the blood and liver. Studies now getting underway will attempt to find reasons for some of these effects. (SWC 12-aA3c)

In a parallel series of investigations, the effect of diet on the uptake of Cu^{64} has been studied. Rats on a low-Cu diet absorbed significantly more of an intraduodenally administered dose of Cu^{64} than did rats on the control diet. This increased disappearance from the intestinal segment in the low-Cu rats was paralleled by increased Cu^{64} contents in several sampled tissues. There were some large differences between the concentrations of stable Cu in the tissues of the two groups, even though the rats on the low-Cu diets had no external symptoms of copper deficiency. The livers and kidneys of the control rats averaged about three times as much Cu as these same tissues from rats fed the low-Cu diet. (SWC 12-aA3c)

In addition to the studies where Cu was administered intraduodenally, some of the rats were dosed subcutaneously with Cu^{64}. When this method of administration was used, 17 percent of the dose could be recovered in the blood, kidneys, heart, liver, and spleen of the control animals after 3 hours, but only 13.6 percent was accounted for in these same tissues in the low-Cu rats. This is in contrast to the results obtained with intraduodenal administration of the isotope in that the tissues from the low-Cu rats consistently took up more of the isotope than tissues from the controls when the dose was placed in the intestinal segment. (SWC 12-aA3c)

In another experiment, the low-Cu diet and the control diet were each fed with and without an addition of 50 p.p.m. of Zn. This study

produced Cu-deficient rats as evidenced by growth and hemoglobin levels. Five-week weight gains of 189; 183; 144; and 125 were obtained for control, + Zn, low-Cu, and low-Cu + Zn diets, respectively, and corresponding hemoglobin levels were 13.5, 12.6, 10.1, and 7.2. Disappearance of Cu^{64} from the intestinal segments was lower in the Cu-adequate than in Cu-deficient rats, but Zn did not significantly affect disappearance or tissue uptake of Cu^{64} in either case. Concentrations of stable Cu were much lower in tissues from the Cu-deficient than in tissues from the control animals. The addition of Zn caused a modest decrease in the stable Cu concentrations with both Cu-deficient and Cu-adequate diets. (SWC 12-aA3c)

2. The copper nutrition of the animal. In a continuing study of the Cu nutrition of the animal and the interrelationships of other nutrients, the effect of the Cu status of the animal on its response to dietary Mo and sulfate has been investigated. In experiments with the rat, it was observed that when the animal's Cu stores were low and a Cu-deficient diet was fed, small amounts of Mo produced toxic symptoms which were intensified by the simultaneous addition of sulfate. However, when the Cu stores and dietary Cu intake were adequate, larger amounts of Mo were required to produce molydenosis, and sulfate completely prevented the harmful effects of Mo. (SWC 12-aA3c)

Thus, the addition of sulfate to Mo-toxic diets produced entirely different results, depending upon whether these diets were fed to Cu-depleted or Cu-adequate animals. When Cu-depleted rats were fed Mo, the primary effect was an accentuation of the metabolic lesions of Cu deficiency; the symptoms being anemia, rough coats, and poor growth. Only Cu corrected this syndrome, and it was exacerbated by sulfate or methionine. On the other hand, the principal symptom associated with molybdenosis in Cu-adequate rats was poor growth, and this was corrected by dietary sulfate and alleviated by methionine. The fact that additional Cu had no corrective effect indicated that Mo was not interfering significantly with Cu metabolism in this instance. (SWC 12-aA3c)

An analysis of the Cu stores in the livers of these animals revealed that the frequently suggested direct relationship between Cu intake and Cu storage does not always obtain. All Cu-depleted animals fed diets containing essentially no Cu had very low liver-Cu levels; with 3 p.p.m. of Cu added to the basal diet of the depleted rats, the liver-Cu levels were normal irrespective of other dietary additions. An approximate doubling of this Cu intake (5.33 p.p.m. Cu) for the Cu-adequate rats did not increase the Cu stores of these animals above those of the Cu-depleted animals receiving 3 p.p.m. of Cu. However, when a high level of Cu (300 p.p.m. Cu) was fed to the Cu-adequate animals, their liver-Cu stores were increased very significantly. (SWC 12-aA3c)

An understanding of the function of Cu, and of the role of those nutrients which interfere with its proper function, is essential before definitive recommendations for the Cu requirement of the animal are possible. Future studies are planned of these interactions and of enzymes which may be concerned with the Cu metabolism of the animal. These findings are of great value in diagnosing some of the congenital malfunctions of livestock in many parts of the country, but particularly among grazing animals of the West. (SWC 12-aA3c)

C. Soil and Plant Composition as Factors Affecting the Distribution of Nutritional Problems in Livestock

1. Selenium. In order to gain a better understanding of the influence of the level of soil and plant micronutrient elements to certain endemic nutritional animal diseases, the project has continued at the laboratory. Experimental data have provided convincing evidence of the importance of soil and plant selenium to the incidence of white muscle disease (W.M.D.). In an area with a high incidence of W.M.D., 2 pounds of Se per acre were added to the soil in part of an alfalfa field. Hay produced on this Se-treated part of the field contained 2.6 p.p.m. Se and was fed to 20 ewes during the last 100 days of gestation and the first 42 days after the birth of the lambs. Hay from the untreated part of the field contained 0.03 p.p.m. Se and was fed under comparable conditions to a similar lot of 20 ewes. The lambs born to ewes fed treated hay showed no clinical, biochemical, or microscopic evidence of W.M.D. Over 70 percent of the lambs born to the ewes fed untreated hay showed clinical and microscopic evidence of W.M.D., and had elevated levels of the enzyme glutamic-oxaloacetic transaminase in their blood. Twenty-five percent of the lambs born to ewes fed untreated hay died from W.M.D. before reaching 6 weeks of age. Thus, the Se added to the soil and taken up by the plant provided complete protection from W.M.D. (SWC 12-aA3c)

In a laboratory study, alfalfa grown in greenhouse soil treated with Se and S was fed to chicks and rats. The Se contained in the alfalfa was found to be of the same value as inorganic selenite in the promotion of growth of both chicks and rats, and in the prevention of liver necrosis in rats. The Se in alfalfa grown at a high level of available S in the soil was about 25 percent less effective than Se in a low-S alfalfa and inorganic selenite for the prevention of exudative diathesis in chicks. These results indicate that critical levels of Se in animal diets, established by the technique of adding inorganic selenite to low-Se feeds, are generally applicable to "field" cases of Se deficiency, where the dietary Se comes from alfalfa. Selenium levels in plants of less than 0.05 to 0.10 p.p.m. indicate potential Se deficiency, with the critical level in specific cases being dependent on the level of vitamin E in the diet. (SWC 12-aA3c)

An experiment conducted to provide information on the availability to plants of Se added to 7 different soils showed there were marked differences in the amounts of Se taken up by alfalfa from different soils. A Mardin soil from New York, treated with Se equivalent to 1 pound per acre, produced alfalfa containing levels of Se that would have provided protection for animals, while the same amount of selenium added to a Lakeland sand from Florida resulted in alfalfa that contained toxic concentrations of Se, and drainage water that contained sufficient Se to represent a potential contamination of ground waters. Studies of the chemical mechanisms responsible for these wide differences in the availability of Se added to different soils are under way. (SWC 12-aA2)

Preliminary results of studies on the biochemistry of Se in plants indicate that much of the Se taken up by alfalfa is metabolized within the plant to form the Se analogue of the sulfur amino acid methionine. Over half of this seleno-methionine is combined into protein. The Se analogue of the amino acid cystine has not yet been detected in alfalfa. These studies will be continued to determine the forms of Se in several plant species. (SWC 12-aA2)

A map of the United States showing the areas where plants contain critically low levels of Se is being prepared in cooperation with the Soil Conservation Service. This map is based on the determination of the Se content of forage species grown on specific soils in specific locations. This map will be very useful to veterinarians and nutritionists in appraising the possibility of Se deficiencies in livestock in different areas. (SWC 12-aA1)

2. Cobalt. After 15 years, studies of the cobalt content of plants as related to Co deficiency in animals are being summarized, and a new map showing areas of potential Co deficiencies in animals, is being prepared. The results of this study show that there are some areas, the New England and South Atlantic States being the most extensive, where all forage crops, including both grasses and legumes, contain too little Co to meet the needs of cattle and sheep. (SWC 12-aA1)

3. Mineral composition of wildlife feeds. A study of the mineral composition of browse plants in relation to soils of the Kenai Peninsula and Aleutian Islands of Alaska is underway in cooperation with the Soil Conservation Service, the U. S. Fish and Wildlife Service, and the Alaska Agricultural Experiment Station. Results to date indicate that the Co and Cu contents of browse plants in these areas are probably adequate to meet the needs of ruminant game animals such as moose. A low S content in twigs of some plants may indicate a potential winter deficiency of this element. This point is being checked with additional samples taken in 1964. (SWC 12-aA1)

4. Grass tetany. Research on some of the soil and plant factors associated with the occurrence of grass tetany or hypomagnesaemia has been started. This problem occurs frequently in the early spring when animals are turned out on the new growth of cool-season grasses. This work, therefore, is being centered first on a study of the effects of temperature upon the levels of K, N, and Mg in different forage species. (SWC 12-aA2)

D. Chemistry of Micronutrients in Soil

1. The complexing of trace elements in soil solutions. Characterization of complexing agents in soil solutions of New York soils has continued with the separation of two predominant types of complexing agents. The first is a strong acid capable of complexing Cu and Zn at pH values as low as 2.0. It is present in low concentrations (less than 10^{-4}), but accounts for the greater part of the complexing strength in the soil solutions studies. The second is a weak acid which is present in larger concentrations. It can be separated from the more acid components by dialysis. Amino acids are also present in the soil solution and may contribute to the complexing of at least Cu at higher pH values. Characterization is continuing with paper chromatographic separation of each of the two components. (SWC 12-aA5)

A study has been initiated on the levels and complexing of Cu and Zn in soil solutions of calcareous soils. Twenty-one soils have been collected from Zn-deficient and Zn-sufficient areas of Colorado. Preliminary results indicate that Cu is complexed more strongly than in corresponding acid soils of New York. (SWC 12-aA5)

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AREA 13: FERTILIZER TECHNOLOGY INVESTIGATIONS, RESOURCES, PRODUCTION, AND IMPROVEMENT

Problem. In a rapidly shifting agricultural economy, fertilizers must be fitted to the changing needs if the farmer is to realize maximal returns for each dollar invested in fertilizer and protect his profits against inevitable rising costs. Manufacturing procedures, insofar as they influence nutrient content, nutrient quality, and physical character of the fertilizer, must be aligned with use benefits in order to permit the design of products that are fully adapted to the service requirements of different crops under particular management practices.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program at Beltsville, Maryland, involving inorganic and physical chemists, a soil scientist, a commodity analyst, and a chemical engineer engaged in basic chemical and physical studies and the application of known principles to the solution of fertilizer problems in the factory and in field distribution.

The Division scientific effort devoted to research in this area totals 25 professional man-years. Of this number, 12 are devoted to materials development and refinement; 6 to mixed-fertilizer investigations; 5 to standardization of specifications and test procedures for marketed fertilizers; 0 to agricultural chemical additives; and 2 to consumption trends and use patterns.

PROGRAM OF STATE EXPERIMENT STATIONS

Most of the State experiment stations have small fertilizer technology research programs. Most of the stations are cooperating with the Tennessee Valley Authority and the fertilizer industry in evaluating new fertilizer materials in laboratory, greenhouse and field experiments. For example, the Mississippi station compared ammonium phosphate sulfate, ammoniated ordinary superphosphate and nitric phosphate in recent field experiments on wheat and corn. These experimental fertilizers, which were provided by the Tennessee Valley Authority, varied in the percentage of citrate soluble phosphate. Since new fertilizer materials must be evaluated under diverse climatic and soil conditions to establish their worth, similar experiments are being conducted in other States.

The State stations also are investigating the efficiencies of various liming materials, properties of liming materials significant in

neutralizing soil acidity, the value of coarse fractions of agricultural limestone under different cropping systems and nitrogen treatments, new and improved micronutrient materials, mixed fertilizers of differing rates of solution and particle size, use of coatings on fertilizer granules to control rate of solution, and better sampling procedures and methods of analysis for use in fertilizer quality control.

The total State research effort on fertilizer technology investigations is 8 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Materials Development and Refinement

Investigations on the suitability of nitrogen materials for fertilizer use was continued during the year with a 33-material nitrification test. The melamine and urea waste molding powders and the materials prepared from them by heat treatment with and without added urea were included in this year's study. The melamine waste contained 87.3 percent of its nitrogen in water-soluble form, exhibited a low availability index (AI) value and was resistant to nitrification. The materials heated to 90° and 100° C. contained much less soluble N, exhibited AI values of approximately 48, but were no less resistant to nitrification than the unheated waste. The observed nitrification values, however, indicated that both the soluble and insoluble forms of N present were substantially non-nitrifiable. It was concluded, therefore, that this waste alone, or after treatment with urea, offered no promise as a nitrogen material suitable for fertilizer use. (SWC 13-aC8)

By contrast, the urea molding waste contained 82.3 percent of its nitrogen in water-soluble form, exhibited an AI value of 32, and was less resistant to nitrification than the melamine waste. The initial resistance in this case gradually decreased as the incubation period was extended. Heating 3 parts of the urea molding waste with 1 part of urea at 80° and 90° C. for 90 min. did not result in a reaction between the waste and the added urea. Increases in the insoluble N contents and AI values paralleled those obtained by heating the waste alone. The nitrification patterns of the heated mixtures were substantially the same as would be obtained by physically mixing urea with heated urea molding waste. (SWC 13-aC8)

Work on the analytical separation of the nitrogen components in fertilizer by ion exchange techniques was completed during the year. This method was checked against official Association of Official Agricultural Chemists' methods in a series of test solutions that contained water-soluble ammonic, nitric, and amidic nitrogen and found to be accurate. Not only were the results obtained rapidly and with precision and accuracy, but values were obtained for specific forms of nitrogen not presently attainable by AOAC methods. (SWC 13-aC9)

Work on the physical characterization of phosphate fertilizer materials was continued with emphasis on the effect of calcination on phosphate rock character. Physical characterizations of a commercial Florida land pebble rock calcined at various temperatures were measured for comparison with results from rocks from Morocco and Utah. Results show that the surface area decreases with increasing calcination temperature with a relatively sharp break appearing at the intermediate temperatures. There was a progressive decrease in true density with increasing calcination temperature. Calcination at 650° and 950° C. results in an increase in reactivity of the Florida rock over that of the uncalcined material. The new information points to controlled calcination as a possible means of augmenting the reactivity of very unreactive deposits of phosphate rock. (SWC 13-aC11)

The use of calcined phosphate rock in wet-process phosphoric acid manufacture has resulted in conflicting experiences of producers. In some cases, the formation of fouling sludges in the product acid was sharply increased in comparison with acid from uncalcined rock. Since iron and aluminum components in the rock are major causative factors in sludge formation, a study was undertaken of the fate of iron and aluminum in calcined rock. Results for 2 test rocks (Florida and Montana) indicate that, although rate of solubilization does not change with calcination temperature, the amount of iron dissolved shows a pronounced maximum when the rock is calcined at 350° C. From these results, it appears that heat and dilute acid treatment offer promise as a preliminary treatment of the rock to reduce the iron content and consequently sludging in wet-process acid manufacture. (SWC 13-aC11)

During the year, the study of the availability of potassium in cement kiln flue dust was completed. Ten dusts were selected that would supply 50 mg. of K without exceeding the amount of $CaCO_3$ equivalent that would neutralize the exchangeable hydrogen of the soil. The dust applications were supplemented with pure $CaCO_3$ in those cases where the $CaCO_3$ equivalent was less than that required for neutralization. The potassium content of crops grown on Chester and Davidson soil fertilized with potassium chloride was not significantly different from that of crops fertilized with flue dust. Correlation studies indicated that the potassium content of the crop increased as the water-soluble K increased and declined as the silica in the dust increased. (SWC 13-aC14)

Investigation of the release of zinc from glasses was continued during the year. Studies of the influence of the method of preparation and composition of zinc glasses on the solubilization of zinc by ammonium acetate was determined. Within the useful range of composition, the release from frits (unstirred melts) was greater, and less sensitive to differences in composition, than that from homogeneous glasses (stirred melts or remelts). The substitution of equimolar amounts of potassium oxide for sodium oxide or alumina for silica had no effect on the reactivity of frits. (SWC 13-aC15)

During the year, the collaborative study of colorimetric methods for the determination of Fe, Al, Mn, P, and Ti was completed. Sample solutions of limestone, blast furnace slag, and cement kiln dust were prepared by $HClO_4$ digestion or NaOH fusion and sent to the 11 collaborators. Eight of the collaborators reported all 5 elements, 2 reported 4 elements, and 1 reported 2 elements. As a result of this study, the methods were adopted as official, first action methods of the AOAC. (SWC 13-aC17)

B. Mixed Fertilizer Investigations

Work on the effect of physical character of nutrient materials on the granulation of fertilizer materials was continued during the year with emphasis on the effect of variation in the particle size limits and the average particle size of the ingredients on the granulation efficiency of the mixtures. Results show that decreasing the particle size limits tends to increase the moisture requirement, and to make the mixture more sensitive to small variation in moisture content in the optimum granulation range. (SWC 13-aC6)

Recently published results of experimental and plant-scale tests on the granulation of mixed fertilizers containing potassium nitrate were correlated with the solubility-temperature relationships of the salt. Laboratory solubility tests and liquid phase analyses of mixtures containing potassium nitrate were conducted in connection with the study. It was demonstrated that the high solubility coefficient of potassium nitrate in the temperature range between 68° F. (ambient temperature) and 194° F. (granulation temperature) is beneficial to the processing and storage of mixed fertilizers. Its high solubility at the ammoniation temperature (194° F.) increases the liquid-phase content of the mixture and improves granulation. The rapid decrease in solubility with drop in temperature following ammoniation decreases the proportion of liquid phase, inhibits the formation of oversize nodules, causes rapid crystal knitting within the granule, and improves the shape and stability of the granule. (SWC 13-aC6)

Sulfur, commonly referred to in fertilizer technology as a secondary element, has long been recognized as an essential plant nutrient. High-analysis fertilizers, such as concentrated superphosphate, diammonium phosphate, ammonium nitrate, urea, potassium nitrate, and high-grade potassium chloride, containing little or no sulfur, are being used in increasing quantities for crop production. A study was initiated to determine the behavior of elemental sulfur in acid-rock mixtures during the preparation of concentrated superphosphate, the distribution of sulfur in the final product, and the effect of sulfur on the ammoniation and granulation characteristics of the product. Results showed that the sulfur added to the acid before acidulation gave consistently better distribution of sulfur in the granular product than where it was added to the rock

before acidulation or to the disintegrated product before granulation. Added sulfur had no appreciable effect on the efficiency of ammonia absorption by the products. (SWC 13-aC6)

C. Standardization of Specifications and Test Procedures for Marketed Fertilizers

Work concerned with the improvement of methods of sampling and analysis of fertilizers, liming materials, and other soil amendments and with the promotion of uniformity in trade specifications was continued. Developments affecting methods for phosphorus includes the adoption of the quimociac modification of the gravimetric quinoline molybdate method as official, final action and the final action repeal of the old gravimetric magnesium ammonium phosphate procedure. The volumetric ammonium advocated by the National Plant Food Institute (NPFI) and the one developed by chemists at TVA, were compared in ruggedness tests. The two procedures were compared collaboratively with the official 'quimociac' QM method by 27 analysts using 10 fertilizer samples. The NPFI procedure gave slightly higher values and the TVA procedure gave lower values than those by the QM procedure. However, statistical evaluation of the data indicated no significant differences between the three procedures. Other considerations indicate that the TVA procedure may well be the answer to the need for having a volumetric method among the official AOAC methods. (SWC 13-aC4)

During the year, an active program on nitrogen analysis was initiated. The application of the Coleman Nitrogen Analyzer to fertilizer nitrogen analysis and the nitrate content of vegetables was studied. Data show that good recoveries for total nitrogen were possible on mixed fertilizers when compared to the Kjeldahl procedure. However, when pure salts were analyzed, the results were high. The instrument proved to be a good tool in surveying the nitrate in vegetables. The survey showed that the nitrate content of vegetables has increased a great deal in the past 50 years. Although the level was not high enough to be of immediate concern to the consumer, the influence of fertilizer practices on the nitrate level of vegetables needs further study. (SWC 13-aC4)

Collaborative results showed the vacuum oven method for determining free water in fertilizer to be as precise as and more rapid than the vacuum desiccation method. This method has been adopted by the AOAC as an official first action method. Titration of the solutions with Karl Fischer reagent gave high results for triple superphosphate in comparison to results by the official 100° oven method. With normal superphosphate, results were lower, owing to the presence of the hydrated precipitate. The findings suggest that the official method is not quantitative for total water, substantiating the published conclusion that monocalcium phosphate is not completely dehydrated on heating in air even at 170° C. (C.A. 52: 1823a). (SWC 13-aC4)

E. Consumption Trends and Use Patterns

The annual report on the consumption of commercial fertilizers and primary plant nutrients in the United States for the year ended June 30, 1963, was completed. Total consumption of commercial fertilizer during this period amounted to 28,844,480 tons, an increase of 8.4 percent over the previous year. This total comprises 17,156,913 tons of mixed fertilizers and 10,228,974 tons of primary nutrient and 1,458,593 tons of secondary and trace nutrient materials used for direct application. Consumption of these three categories increased 5.9, 12.4, and 11.4 percent, respectively, over consumption in 1961-62. Consumption of primary nutrients in 1962-63 and the percentage gains in parenthesis over 1961-62, was as follows: Nitrogen, 3,929,089 (16.6); available phosphoric oxide, 3,072,873 (9.5); and potash, 2,503,462 (10.3). (SWC 13-aC1)

There is still a strong upward tend in the use of liquid nitrogen fertilizer materials, including anhydrous ammonia. Consumption in 1962 and 1963 was 25.8 percent higher than in the previous year, and the greatest percentage increase occurred in the use of anhydrous ammonia. (SWC 13-aC1)

Global development of the fertilizer industry continued at a fast pace during 1964. The greatest interest has been in the construction and expansion of ammonia production facilities with urea and ammonium sulfate as the final solid end products. There has been a marked shift in the English-speaking countries to the production and use of ammonium nitrate. These semiannual reports have been a source of information for domestic companies entering foreign markets, and they are being used by personnel in Departments of the Interior, Commerce, State (Agency for International Development), Tennessee Valley Authority, as well as Services in Agriculture. Several officers in the United Nations (Italy) have requested that their names be placed on the mailing list. (SWC 13-aC13)

The 1959 estimates of the use of commercial fertilizer on crops and pasture in the United States were completed. The report includes estimates of fertilizer use on individual crops in terms of principal plant nutrients for 1959 for the 50 States, Puerto Rico, and each of 99 agricultural subregions in the 48 contiguous States. The data provide benchmarks that are widely used by public and private agencies and individuals in analyzing trends and in making studies of farm adjustment problems as they relate to changing patterns of fertilizer use. Comments from industry state that this work is "valuable enough to them to hope that you will continue to do this type of survey even at 5-year intervals and even 5 years late." (SWC 13-aC16)

On December 31, 1964, Secretary Freeman announced a plan for reducing the research effort for certain projects in the Department of Agriculture. The U. S. Fertilizer Laboratory at Beltsville was included in the locations to be closed. The plan is for the Tennessee Valley Authority to assume the full Federal responsibility for fertilizer technology research, while the statistical reporting will be the responsibility of another Agricultural agency. Therefore, this report will be a terminal report for the fertilizer technology investigations in the Division.

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Line Project Check List -- Reporting Year April 1, 1964 to March 31, 1965

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 1	Sedimentation processes in relation to watershed development and protection.			
SWC 1-a1	Development and evaluation of means and measures for channel stabilization in the Northeast.	East Aurora, N. Y.	Yes	1-C-1, D-1, 2
SWC 1-b1	Sediment production, yield and delivery ratio in relation to climatic factors and watershed characteristics in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Holly Springs, Miss. Cartersville, Ga.	Yes	1-A-1,2,3 B
SWC 1-b2	Investigations of the nature and processes of reservoir sedimentation in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss	No	
SWC 1-b3	Mechanics of sediment entrainment, transporation and deposition in natural and artificial channels in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	Yes	1-C-1
SWC 1-b4	Investigations of stream channel morphology in the Southern Branch and at the U.S. Sedimentation Laboratory	Oxford, Miss Watkinsville, Ga. Ft. Lauderdale, Fla.	Yes	1-A-1, D-2, 3
SWC 1-b5	Development of structural measures for sediment control and for stream channel stabilization in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss	No.	
*SWC 1-7(c-1)(R)	Sediment sources and yields in agricultural watersheds in Corn Belt States.	Columbia, Mo. Council Bluffs, Ia. Coshocton, Ohio	Yes	1-A-3
*SWC 1-17(c3)	Reservoir sedimentation studies in Corn Belt States.	Columbia, Mo.	No	
SWC 1-d2	Sediment production, yield, and delivery ratio in relation to climatic, geologic, and watershed characteristics of the Northern Plains.	Hastings, Nebr. Rosemont, Nebr. Newell, S. Dak.	Yes	1-A-1, 3
**SWC 1-18(d-3)	Factors influencing the stability and regime of channels in agricultural watersheds of the Northern Plains.	Hastings, Nebr.	Yes	1-D-2
SWC 1-e1	Sediment production, movement, and deposition in agricultural watersheds in the Southern Great Plains.	Chickasha, Okla. Riesel, Tex. Sonora, Tex.	Yes	1-A-1, C-1 D-2
SWC 1-e2	Stream channel stabilization and sediment control works in channels in the Southern Great Plains.	Chickasha, Okla. Stillwater, Okla.	Yes	1-D-2
SWC 1-f1	Sediment movement and deposition on upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	No	
SWC 1-g1	Sediment yields of agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Santa Rosa, N. Mex. Moorpark, Calif.	Yes	1-A-1, 3
SWC 1-g2	Stream channel morphology and channel stability on agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Lompoc, Calif. Moorpark, Calif.	Yes	1-D-1, 2
SWC 1-g3	Nature and processes of reservoir sedimentation in the Southwest. *Approved September 8, 1964 **Approved July 30, 1964	Tucson, Ariz. Tombstone, Ariz. Lompoc, Calif. Moorpark, Calif. Santa Rosa, N. Mex.	Yes	1-B

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. In Summary of Progress (Yes-No)	Line Project Incl. In Area and Subheading
SWC 2	Hydrology of agricultural watersheds and associated aquifers in relation to treatment for flood prevention and multiple use of water resources.	Beltsville, Md.	Yes	2-A-5, H
SWC 2-a1	The relation of rain, snow, and frozen soils to the hydrology of agricultural watersheds in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-A-1
SWC 2-a2	Water yield in relation to climatic and watershed characteristics of land resource areas in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-B-4, D-1
SWC 2-a3	Storm runoff and floodflows in relation to climatic and watershed characteristics of land resource areas in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-F-2
SWC 2-aD1	Analytical hydrography in watershed engineering.	Beltsville, Md.	Yes	2-A-1,B-1, F-2,3
SWC 2-b1	Relation of climatic and watershed factors to runoff rates and volume yields in the Southern Branch	Ft. Lauderdale, Fla. Oxford, Miss.	Yes	2-B-4,E, F-1
SWC 2-b2	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Branch	Ft. Lauderdale, Fla. Oxford, Miss.	Yes	2-A-1,2,3
SWC 2-b3	Runoff production by unit source area agricultural watersheds in the South	Oxford, Miss. Holly Springs, Miss. Watkinsville, Ga.	Yes	2-G-1
SWC 2-b4	Subsurface and ground water accretion, depletion, movement and contribution to streamflow for agricultural watersheds in the Southern Branch.	Oxford, Miss. Ft. Lauderdale, Fla.	Yes	2-B-2,C-1, D-1,2
SWC 2-c1	Precipitation and snowmelt characteristics influencing runoff from agricultural watersheds in Corn Belt States.	Coshocton, Ohio	No	
SWC 2-c2	Runoff production by unit source area agricultural watersheds in Corn Belt States.	Coshocton, Ohio	No	
SWC 2-c3	Relation of climatic and watershed factors to storm runoff in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Council Bluffs, Ia. Madison, Wisc. Fennimore, Wisc.	Yes	2-B-1,2, F-1
SWC 2-c4	Relation of climatic and watershed physiographic and cultural factors to water yield in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Madison, Wisc. Fennimore, Wisc.	No	
SWC 2-c5	Aquifer and subsurface relationships in the hydrology of upstream agricultural watersheds in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Madison, Wisc. Fennimore, Wisc.	Yes	2-D-1
SWC 2-27(c6)	Soil moisture regimes of agricultural watersheds in Corn Belt States.	Coshocton, Ohio Columbia, Mo. Council Bluffs, Ia. Madison, Wisc.	No	
SWC 2-d1	Water yield as related to integrated climatic and watershed characteristics in the Northern Plains.	Hastings, Nebr. Rosemont, Nebr. Newell, S. Dak. Cottonwood, S. Dak.	Yes	2-E
SWC 2-d2	Storm runoff and floods as related to integrated climatic and watershed characteristics in the Northern Plains.	Hastings, Nebr. Rosemont, Nebr. Newell, S. Dak. Cottonwood, S. Dak.	Yes	2-F-1

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 2-e1	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Plains.	Chickasha, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-A-1, 2
SWC 2-e2	Runoff production by unit source areas in the Southern Plains.	Stillwater, Okla. Cherokee, Okla. Chickasha, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-B-2
SWC 2-e3	Relation of climatic and watershed factors to storm runoff in the Southern Plains.	Chickasha, Okla. Stillwater, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-E, F-1, 3
SWC 2-e4	Relation of climatic and watershed physiographic and cultural factors to water yield in the Southern Plains.	Chickasha, Okla. Stillwater, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-C-1, 2 D-2, E
SWC 2-f1	Aquifer-streamflow interrelationships in upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	Yes	2-A-5, C-2
SWC 2-f2	Precipitation characteristics influencing hydrologic performance of agricultural watersheds in the Pacific Northwest.	Boise, Idaho Moscow, Idaho	Yes	2-A-2, 5
SWC 2-f3	Runoff and sediment movement on unit source watersheds of the Pacific Northwest as influenced by climate, soils, vegetation, and topography.	Boise, Idaho Moscow, Idaho	Yes	2-B-3
SWC 2-f4	Water accumulation, flood-wave movement and water yield from complex watersheds of the Pacific Northwest.	Boise, Idaho Moscow, Idaho	Yes	2-A-1, E
SWC 2-g1	Precipitation characteristics influencing the hydrology of agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Santa Rosa, N. Mex. Lompoc, Calif. Tehachapi, Calif.	Yes	2-A-1, 3, 4
SWC 2-g2	Relation of integrated climatic, watershed, and cultural factors to storm runoff from agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Santa Rosa, N. Mex. Lompoc, Calif. Logan, Utah	Yes	2-B-2, D-2, E, F-1, G-3
SWC 2-g3	Relation of integrated climatic, watershed, and cultural factors to water yields from agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque, N. Mex. Santa Rosa, N. Mex. Lompoc, Calif.	Yes	2-B-4, C-1, 2 G-2

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 3	Hydraulics of irrigation, drainage and watershed protection and water supply structures, channels, and facilities.			
SWC 3-c1	Hydraulic design of structures for water use and control in the Corn Belt	Minneapolis, Minn.	Yes	3-A-1, B-1, 2,3
SWC 3-e1	The hydraulics and measurement of channel, floodplain, and overland flow in the Southern Plains.	Stillwater, Okla. Chickasha, Okla. Tombstone, Ariz.	Yes	3-A-2, D
SWC 3-e2	Hydraulic design of structures for water use and control in the Southern Plains.	Stillwater, Okla. Chickasha, Okla.	Yes	3-B-4,5
SWC 3-g1	The hydraulics of channel, floodplain and overland flows in the Southwest	Tombstone, Ariz. Santa Rosa, N. Mex. Albuquerque, N. Mex. Logan, Utah	Yes	3-C

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress (Yes-No)	Line Proj. Incl. in Area and Subheading
SWC 4	Conservation of water supplies for agricultural use			
SWC 4-b1	Development of water supplies for irrigation in the South	Tifton, Ga.	Yes	4-B-1
*SWC 4-14(b2)	The disposition of pesticides in soil and closely related water	Watkinsville, Ga. Baton Rouge, La.	Yes	4-D-1
SWC 4-c1	Improvement of water supply sources and storage facilities in the Corn Belt	McCredie, Mo.	Yes	4-B-1
**SWC 4-3(d1), (Rev.)	Facilities, methods and design criteria to pump, convey, control and measure water for agricultural purposes in the Northern Plains	Ft. Collins, Colo. Akron, Colo. Mandan, N. Dak. Newell, S. Dak.	Yes No No Yes	4-B-2,D-1
SWC 4-13(e2)	Facilities and procedures for conservation management of runoff water from agricultural lands in the Southern Plains	Hays, Kans. Bushland, Tex. Weslaco, Tex.	No Yes No	4-B-3, C
SWC 4-g1	Control of water use by nonbeneficial plants and evaporation losses from storage and conveyance structures in the Southwest	Humboldt River Basin, Nev. Watsonville, Calif.	Yes	4-D-1, 2
SWC 4-g2	Recharge facilities, methods, principles and design criteria for storing water in underground reservoirs in the Southwest	Fresno, Calif.	Yes	4-C
SWC 4-g3	Control of agricultural water supply and conveyance seepage losses in the Southwest	Fallon, Nev. Yerington, Nev. Reno, Nev. Logan, Utah	Yes	4-A-1, B-1
SWC 4-gG1	Measurement, evaluation and control of seepage losses	Tempe, Ariz.	Yes	4-A-1
SWC 4-gG2	Atmospheric and related boundary mechanisms in water vapor losses from plant, soil and water surfaces	Tempe, Ariz.	Yes	4-A-2, 3
SWC 4-gG3	Measurement, evaluation and control of infiltration to conserve water	Tempe, Ariz.	Yes	4-B-1, C
SWC 4-gG4	Physical processes in the soil affecting preventable losses of water by surface evaporation	Tempe, Ariz.	Yes	4-A-2
SWC 4-gG5	Water measurement and control for water conservation	Tempe, Ariz.	Yes	4-B-2
A10-SWC-25	Removal of suspended matter and turbidity from water by flocculation with polyelectrolyte coagulants and coagulation acids	Haifa, Israel	Yes	4-C
A10-SWC-29	Studies of the influence of plant and environmental factors on photosynthesis, stomatal aperture and transpiration	Rehovot, Israel	No	
A10-SWC-36	Runoff inducement in arid lands	Rehovot, Israel	No	

* Approved February 25, 1965

** Approved September 8, 1964

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Proj. Incl. in Summary of Progress (Yes-No)	Incl. in Area and Subheading
SWC 5	Irrigation principles, requirements, practices, and facilities for efficient use of water on farms			
SWC 5-a1	Irrigation practices and factors affecting the water requirement of crops in different land resource areas in the Northeast	New Brunswick, N. J Blacksburg, Va. Norfolk, Va.	Yes	5-A-1,2,3
SWC 5-b1	Irrigation requirements, practices and methods of application for efficient production of crops in the Southeast	Thorsby, Ala. Ft. Lauderdale, Fla. Watkinsville, Ga. Tifton, Ga. State College, Miss.	Yes	5-A-1,2, B-3
SWC 5-c1	Improvement in performance and design of irrigation systems in the Corn Belt	Columbia, Mo.	No	
SWC 5-d1	Irrigation practices, requirements and design criteria for efficient use of water and sustained crop production in the Northern Plains	Ft. Collins, Colo. Grand Junction, Colo. Gunnison, Colo. Lincoln, Nebr. Newell, S. Dak. Fontenelle, Wyo. Laramie, Wyo.	Yes	5-A-1, B-1, C-2
SWC 5-5(e1)Rev.	Irrigation water management for efficient water use in the Southern Plains	Bushland, Tex. Weslaco, Tex.	Yes	5-A-1,2, C-1
SWC 5-f1	Irrigation requirements, principles and practices for efficient use of water in the Pacific Northwest	Twin Falls, Ida. Ontario, Ore. Prosser, Wash.	Yes	5-A-1,3
SWC 5-f2	Surface and sprinkler design and operation principles and facilities for efficient water use in the Pacific Northwest	Twin Falls, Ida.	Yes	4-B-2, 5-B-2, C-1, 2
*SWC 5-8(g1)(R)	Improved irrigation water application systems for the Southwest	Riverside, Calif. Reno, Nev. Logan, Utah Milford, Utah	Yes	5-B-1,2,3, C-1
**SWC 5-9(g2)(R)	Irrigation requirements of forage and cultivated crops in the Southwest	Riverside, Calif. Reno, Nev. Tempe, Ariz.	Yes	5-A-1,2
A10-SWC-5	Performance and scientific design of sprinklers used for irrigation	Haifa, Israel	No	
A10-SWC-11	Further studies on the Blaney and Criddle formula V=KF to ascertain the consumptive use of water by plants by means of analysis of climatological data	Rehovoth, Israel	Yes	5-A-1
A10-SWC-19	The effects of considerable reduction in the intensity of sprinkling irrigation for increased yields, decrease in water duty and improved soil conditions.	Rehovoth, Israel	No	

*Approved December 7, 1964

**Approved November 24, 1964

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 6	Drainage principles, requirements, practices, and facilities for protection of crops and soils			
SWC 6-a1	Development and evaluation of surface and subsurface drainage practices in different land resource areas of the Northeast	Blacksburg, Va. Norfolk, Va. Burlington, Vt.	Yes	6-A-1, D-1, 3
SWC 6-b1	Drainage requirements of crops in the South	Ft. Lauderdale, Fla. Raleigh, N. Car.	Yes	6-D-1, 3
SWC 6-b2	Design, installation and maintenance of surface and subsurface drainage systems with or without landforming and conditioning in the South	Fleming, Ga. Baton Rouge, La. Raleigh, N. Car.	Yes	6-A-2, D-2
SWC 6-c1	Improvement and modernization of surface and subsurface drainage practices and facilities in the Corn Belt	Urbana, Ill. Morris, Minn. Minneapolis, Minn. Columbus, Ohio Madison, Wisc.	Yes	6-B-1, 2, D-2, 3
SWC 6-d1	Drainage facilities, methods, and design criteria for protection and improvement of agricultural crops and soils in the Northern Plains	Ft. Collins, Colo. Grand Junction, Colo. Grand Forks, N. Dak.	No	
*SWC 6-12(e3)	Improved drainage systems design, materials, installation techniques and drainage requirements of crops in the Southern Plains	Weslaco, Tex.	Yes	6-B-2
SWC 6-g1	Basic drainage principles in the Southwest	Brawley, Calif. Logan, Utah	Yes	6-D-2
SWC 6-g2	Drainage facilities, methods and evaluation for irrigation lands in the Southwest	Brawley, Calif. Reno, Nev. Logan, Utah	Yes	6-B-1, 3
SWC 6-g3	Drainage and aeration requirements of crops on irrigated lands in the Southwest	Reno, Nev.	No	
SWC 6-gF1	Principles of drainage as related to salt-affected soils in the Southwest	Riverside, Calif.	Yes	6-C

* Approved June 1, 1964

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 7	Saline, sodic, and related soils problems, and quality of irrigation waters and their relation to plant growth processes			
SWC 7-a1	Investigations of the effects of using saline and industrial waste waters on yield and quality of plants and on physical and chemical characteristics of soils in the Northeast	New Brunswick, N. J. Norfolk, Va.	Yes	7-B-3, E
SWC 7-b1	The effect of brackish water on plants and soils in the South	Fleming, Ga.	Yes	7-B-3
SWC 7-d1	Improvement and management of saline and sodic soils of the Northern Plains	Grand Junction, Colo. Grand Forks, N.Dak. Mandan, N. Dak. Huntley, Mont.	Yes	7-D
SWC 7-e1	Saline and sodic soils and irrigation water quality problems in the Rio Grande River Basin	Weslaco, Tex.	Yes	7-B-2, D
*SWC 7-18(e2)	Spectral reconnaissance for diagnosis of soil and water management problems	Weslaco, Tex.	Yes	7-A-3
SWC 7-f1	Soil and water management practice for the control or alleviation of saline and sodic soil problems in the Pacific Northwest	Ontario, Ore.	Yes	7-D
SWC 7-g1	Effect of leaching, amendments, water quality and soil and crop management practices on the soluble salt and absorbed cation status of salt-affected southwestern soils	Riverside, Calif.	No	
SWC 7-gF1	Mechanisms of reactions between dissolved and adsorbed constituents of salt-affected soils	Riverside, Calif.	Yes	7-A-1
SWC 7-gF2	Structure, organic matter, and microbial relations in salt-affected soils	Riverside, Calif.	Yes	7-A-2
SWC 7-gF3	Methods for the diagnosis and study of salinity in soils and water	Riverside, Calif.	Yes	7-A-3
SWC 7-gF4	Soil physical and chemical conditions in relation to plant growth on salt-affected soils	Riverside, Calif.	Yes	7-A-4
SWC 7-gF5	Tolerance of economic plants to salinity and exchangeable sodium	Riverside, Calif.	Yes	7-B-2
SWC 7-gF6	Plant-water relationships under saline, drought, or high exchangeable-sodium conditions	Riverside, Calif.	Yes	7-B-1
SWC 7-gF7	Effects of salinity and exchangeable-cation status on absorption, distribution, and metabolic effectiveness of ions in plants	Riverside, Calif.	Yes	7-B-1
SWC 7-gF8	Effects on plants of specific ions associated with salinity or exchangeable sodium	Riverside, Calif.	Yes	7-B-2
SWC 7-gF9	Influence of climatic and edaphic factors on plant response to salinity and exchangeable sodium	Riverside, Calif.	No	
SWC 7-gF10	Chemical composition of irrigation waters in relation to their suitability for use	Riverside, Calif.	Yes	7-C

* Approved January 11, 1965

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 7-gF11	Principles of salinity control, including the amelioration of salt-affected soils by leaching and the use of amendments	Riverside, Calif.	Yes	7-E
A10-SWC-7	The response of plants to changing salinity	Jerusalem, Israel	No	
A10-SWC-24	Development of methods for measuring partial vapor pressure in soil water	Haifa, Israel	No	
A10-SWC-31	Theoretical and experimental investigations of the mechanism of flow of water and solutes in plant roots	Jerusalem, Israel	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 8	Water and wind erosion control principles, practices, systems, and prediction methods for conservation of crop and rangelands.			
SWC 8-a1	Determination and evaluation of factors affecting water runoff and erosion in the different land resource areas of the Northeast as related to soil and water conservation practices	Orono, Me. Presque Isle, Me Ithaca, N. Y. Marcellus, N. Y.	Yes	8-A-1, 3,B-1
SWC 8-b1	Effects of soil, topography, climate, cropping and management procedures on runoff and erosion, and on the prediction of soil losses in the South.	Athens, Ga. Tifton, Ga. Watkinsville, Ga. Holly Springs, Miss.	Yes	8-A-2, B-1, 3, D-2
SWC 8-b2	Development of supporting practices, systems, techniques and devices for runoff and erosion control in the South	Watkinsville, Ga.	Yes	8-A-1, D-2
SWC 8-c1	Basic principles and mechanics of rainfall, runoff, soil movement and loss	Urbana, Ill. Lafayette, Ind. Morris, Minn. Brookings, S. Dak.	Yes	8-A-1
SWC 8-c2	Evaluation of climatic, topographic, soil, and crop management factors in relation to water management and erosion control.	Ames, Iowa Beaconsfield, Iowa Castana, Iowa Independence, Iowa Lafayette, Ind. Morris, Minn. Columbia, Mo. McCredie, Mo. Brookings, S. Dak. LaCrosse, Wisc.	Yes	8-A-2, B-1
SWC 8-c3	Development and refinement of methods for predicting field runoff and soil loss.	Lafayette, Ind.	Yes	8-C-1
SWC 8-c4	Development of supporting runoff and erosion control practices and systems	Crookston, Minn. McCredie, Mo.	No	
*SWC 8-8(d1)Rev.	Water and wind erosion and its control on irrigated and nonirrigated lands in the Northern Plains	Sidney, Mont. Hastings, Nebr. Lincoln, Nebr.	Yes	8-B-1, 3
SWC 8-e1	Wind erosion control in the Southern Plains	Colby, Kans. Garden City, Kans. Hugoton, Kans. Manhattan, Kans. Alliance, Nebr. Big Spring, Tex. Bushland, Tex.	Yes	8-A-3, B-2, C-2, D-1
SWC 8-10(e2) Rev.	Mechanics and principles of water erosion and their application for erosion control in the Southern Plains	Manhattan, Kans. Cherokee, Okla. Chickasha, Okla. Temple, Tex.	Yes	8-A-3, D-2, 3
SWC 8-f1	Erosion and runoff control practices and systems to conserve soil and water resources in the Pacific Northwest	St. Anthony, Ida. Pendleton, Ore. Pullman, Wash. Rockford, Wash.	Yes	8-B-1, D-4
SWC 8-f2	Fundamental aspects of water erosion in the Pacific Northwest	Pullman, Wash.	Yes	8-A-1

* Approved September 8, 1964

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl.in Summary of Progress (Yes-No)	Line Project Incl.in Area and Subheading
SWC 9	Moisture conservation for the efficient and effective use of precipitation on crop and range lands.			
*SWC 9-1(c1)(R)	Development of soil management systems for efficient use of soil moisture in the Corn Belt region.	Morris, Minn. Brookings, S. Dak. Madison, S. Dak. Ames, Iowa Lancaster, Wisc.	Yes	9-A-1
SWC 9-d1	Improved water conservation and use on nonirrigated lands of the Northern Plains.	Akron, Colo. Ft. Collins, Colo. Gunnison, Colo. Bozeman, Montana Sidney, Montana Lincoln, Nebr. North Platte, Nebr. Mandan, N. Dak. Cottonwood, S. Dak. Newell, S. Dak. Laramie, Wyo.	Yes	9-A-2,3,4,5 B-1,3 C-2,3,4
SWC 9-e1	Conservation and efficient use of precipitation in the Southern Great Plains.	Big Spring, Tex. Bushland, Tex. Temple-Riesel, Tex. Weslaco, Tex.	Yes	9-A-2, B-2, C-6,7
SWC 9-f1	Moisture conservation principles and practices in the Pacific Northwest.	St. Anthony, Idaho Newdale, Idaho Pendleton, Ore. Moro, Ore.	Yes	9-C-3,5
SWC 9-g1	Perfecting cropping sequences, land and water management systems, and cultural practices to conserve and efficiently utilize precipitation.	Riverside, Calif.	Yes	9-C-1,7

* Revised August 19, 1964

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 10	Soil properties, processes and management in relation to the conservation and efficient use of land and water resources.			
SWC 10-a1	Development of improved soil management and conservation practices on croplands in different land resource areas of the Northeast.	Orono, Maine Marlboro, N.J. Marcellus, N. Y. Blacksburg, Va.	Yes	10-C-2,5 11-B-3
SWC 10-a2	Development of improved soil management practices for grassland soils in different land resource areas of the Northeast.	University Park, Pa.	Yes	10-A-3,5
SWC 10-36(a3)	Fixation of atmospheric nitrogen by rhizobia.	Beltsville, Md.	No	
SWC 10-aB1	Fixation of ammonium ion in soils and its release to plants	Beltsville, Md.	No	
SWC 10-aB2	Biological transformations of nitrogen in soil, including biological interchange in the rhizosphere, nonsymbiotic fixation, gaseous losses, and accumulation of toxic products.	Beltsville, Md.	No	
SWC 10-aB3	Humus formation in soils and the interaction of organic compounds with clays.	Beltsville, Md.	Yes	10-D-1
SWC 10-aB4	Evaluation of soil-pesticide complexes, including their decomposition.	Beltsville, Md.	Yes	10-B-2
SWC 10-aB6	Genetic studies with nitrogen-fixing organisms.	Beltsville, Md.	Yes	10-D-2
SWC 10-aB7	The relationship between the soil as the source of nutrients and the ion uptake process in the plant.	Beltsville, Md.	Yes	10-B-1
SWC 10-aB8	Nutrient balance for plant growth as related to soil environment, plant species and variety, and the nature of added nutrient carriers.	Beltsville, Md.	Yes	10-B-1
SWC 10-aB9	Development of spectrochemical methods and foliar diagnostic procedures for soil and plant investigations.	Beltsville, Md.	No	
SWC 10-37(aB10)	Physical chemistry of potassium availability in soils.	Beltsville, Md.	No	
*SWC 10-38 (aB11)	The effects of pesticides and other chemical contaminants on microbial processes in soils.	Beltsville, Md.	No	
*SWC 10-39 (aB12)	The agricultural significance of certain transitional elements derived from pesticides and other agricultural chemicals	Beltsville, Md.	No	
SWC 10-b1	The lime requirements of red and yellow podzolic and related soils.	Thorsby, Ala. Jayuya, Puerto Rico Ciales, Orocovis, and Rio Piedras, P. R. Florence, S. Car.	No	
SWC 10-b2	The fertility requirement of exposed subsoils	Cartersville, Ga. Puerto Rico	Yes	10-C-1
SWC 10-b3	Fertilization for efficient crop production under intensive management	Thorsby, Ala. Watkinsville, Ga. Fleming, Ga. State College, Miss. Rio Piedras, P. R.	Yes	10-A-3, B-1, C-2

* Approved January 25, 1965

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress (Yes-No)	Line Project Incl. in Area and Subheading
SWC 10-b4	Developing improved cropping systems for soil conservation.	Fleming, Ga. Watkinsville, Ga. Rio Piedras, P. R. Florence, S. Car.	Yes	10-C-6
SWC 10-b5	Crop residue management and tillage practices for soil conservation and efficient production in the South.	Thorsby, Ala. Watkinsville, Ga. Rio Piedras, P. R. Florence, S. Car.	Yes	10-B-2, C-2
SWC 10-b6	Factors influencing crop rooting development and activity and means of increasing root development in the South.	Auburn, Ala. Thorsby, Ala.	Yes	10-B-1, C-4
SWC 10-b7	Integration of improved practices for soil and water conservation in the South.	Fleming, Ga. Watkinsville, Ga.	No	
SWC 10-c1	Moisture utilization in the Corn Belt as influenced by soil fertility level and management practices.	Morris, Minn. Madison, S. Dak.	No	
SWC 10-c2	Tillage practices and crop residue management for soil conservation and efficient production in the Corn Belt.	Ames, Iowa Morris, Minn. Columbia, Mo. Madison, S. Dak.	Yes	10-C-1, 2
SWC 10-c3	Fundamental studies on the mechanism of soil structure formation in the Corn Belt.	St. Paul, Minn.	Yes	10-C-1
SWC 10-d1	Chemical reactions and availability of phosphates in northern Plains soils as affected by fertilization, soil properties, and management.	Mandan, N. Dak. Grand Junction, Colo. Bozeman, Mont. Huntley, Mont. Ft. Collins, Colo.	Yes	10-A-4
SWC 10-d2	Soil nitrogen transformations in relation to soil nitrogen maintenance and more efficient use of fertilizer nitrogen in the Northern Plains.	Huntley, Mont. Laramie, Wyo. Newell, S. Dak. Mandan, N. Dak. Ft. Collins, Colo. Gunnison, Colo. Grand Junction, Colo.	Yes	10-A-1, 2
SWC 10-d3	Fertilizer requirements and fertility status of Northern Plains soils for more efficient crop and forage production.	Ft. Collins, Colo. Grand Junction, Colo. Gunnison, Colo. Newell, S. Dak. Laramie, Wyo. Huntley, Mont. Bozeman, Mont. Mandan, N. Dak.	Yes	10-A-5
SWC 10-d4	Improved soil management practices and systems for better conservation farming in the Northern Plains.	Akron, Colo. Ft. Collins, Colo. Grand Junction, Colo. Gunnison, Colo. Bozeman, Mont. Sidney, Mont. North Platte, Nebr. Mandan, N. Dak. Newell, S. Dak. Laramie, Wyo.	No	
SWC 10-d5	Principles and practices of stubble-mulch maintenance for soil and water conservation in the Northern Plains.	Akron, Colo. Bozeman, Mont. Sidney, Mont. Lincoln, Nebr. North Platte, Nebr.	Yes	10-C-5, D-1

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*SWC 10-d6	Interrelationships of soil and climate as a basis for predicting applicability of research results, soil response to treatment, and crop yields under different levels of management in the Northern Plains.		No	
**SWC 10-40(d7)	Chemical, physical, and biological reactions of pesticides with soils affecting soil productivity and pesticide stability.	Ft. Collins, Colo.	Yes	10-B-2
SWC 10-e1	Interrelationships between soil structure and plant growth.	Big Spring, Tex. Bushland, Tex. Temple, Tex.	Yes	10-C-1, 3, 4
SWC 10-e2	Nutritional requirements for cropland and rangeland in the Southern Great Plains.	Bushland, Tex. Temple-Riesel, Tex. Weslaco, Tex.	Yes	10-A-3
SWC 10-f1	Soil management practices for conservation farming in the Pacific Northwest.	Pendleton, Ore. Twin Falls, Idaho St. Anthony, Idaho Pullman, Wash. Prosser, Wash.	Yes	10-A-5, C-3, 5
SWC 10-f2	Chemistry and availability of nutrient elements in soils of the Pacific Northwest.	Corvallis, Ore. Pendleton & Moro, Ore. Prosser, Wash.	Yes	10-A-3
SWC 10-f3	Chemistry and effects of organic matter in soils of the Pacific Northwest.	Corvallis, Ore.	Yes	10-A-2
SWC 10-f4	Microbial equilibria in soils of the Pacific Northwest.	Prosser, Wash.	No	
SWC 10-g1	Principles of nutrient uptake and efficient fertilizer use in relation to moisture regime and irrigation practice, soil properties and crop nutrient requirements in the Southwest.	Brawley, Calif. Riverside, Calif. Tucson, Ariz. Logan, Utah	Yes	10-A-3, 4 C-6
SWC 10-g2	Improvement of soil fertility, crop production and soil and water conservation through the use of fertilizers and soil amendments on rangeland and nonirrigated cropland in the Southwest.	Riverside, Calif.	No	
SWC-0-0-1 (AEC)	Soil chemistry and radioactive contamination in soils and plants.	Beltsville, Md.	Yes	10-B-3
A7-SWC-7	A study of the soil algae of the rick fields and their contribution to the fertility of the soil.	University of Allahabad, Allahabad, India	Yes	10-D-2
A7-SWC-17	Iron and molybdenum as plant nutrients	University of Lucknow, Lucknow, India	No	
A7-SWC-29	Investigations on soil structure as influenced by organic matter with the help of microscopic and other techniques.	Indian Agricultural Res. Insti., New Delhi, India	Yes	10-C-1
A10-SWC-1	Agricultural utilization of soils affected by salinity. (executed 1-1-65 for 4-year duration)	Hebrew U., Rehovot, Israel	No	

* Project discontinued May 15, 1964.
** Approved April 9, 1965.

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A10-SWC-8	Mode of occurrence of minor elements in sediments and soils: A fundamental study for the understanding of the behavior and distribution of minor elements in soils.	Hebrew U. of Jerusalem, Israel	No	
A10-SWC-12	The determination of available micro-elements in calcareous soils.	Hebrew U., Rehovot, Israel	No	
A10-SWC-15	Micro-heterometric methods for the quick and precise determination of trace elements in agriculture.	Hebrew U. of Jerusalem	No	
A10-SWC-22	Basic and applied research into efficiency of phosphate fertilization (executed 1-7-65 for 5-year duration)	Technion-Israel Institute of Technology Fert. Development and Soil Fertility Lab., Haifa, Israel	No	
E21-SWC-2	Fundamental studies of reactions between mineral and organic components in soil.	College of Agriculture, Wroclaw, Poland	No	
E21-SWC-3	Studies on the variability and genetics of Rhizobium.	M. Curie-Sklodowska U., Lublin, Poland	Yes	10-D-2
E21-SWC-7	Distribution of micronutrient elements among soil minerals.	The Insti. of Soil Sci. & Plant Cultivation, Pulawy, Poland	Yes	10-D-2
E25-SWC-7	Study of the retention of some substances of insecticidal and weedcontrolling potential by the principal specific clay constituents, and relation of that retention to the specific surface area of the clay constitutents, moisture, and temperature.	U. Granada, Spain	Yes	10-B-2

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SWC 11	Soil, water, and plant relations as they affect use of land and water resources			
SWC 11-a1	The energy budget at the earth's surface	Ithaca, N. Y.	Yes	11-B-1, 2
*SWC 11-b1	Modification of soil surface structure and crop geometry to beneficially influence climatic conditions in the South.	Thorsby, Ala. Watkinsville, Ga. State College, Miss.	Yes	11-B-1
SWC 11-b2	Plant factors influencing transpiration in the South.	Watkinsville, Ga. Florence, S. Car.	Yes	11-B-2
**SWC 11-4(b3)	Gaseous losses of nitrogen under field conditions in the Southern States.		No	
***SWC 11-5(b4)	Reduction of strontium-90 by crops.		No	
SWC 11-c1	Soil moisture-plant growth relationships	Urbana, Ill. St. Paul, Minn.	Yes	11-A-5
SWC 11-c2	Climatic influence on water use and crop performance in the Corn Belt region.	Urbana, Ill. Morris, Minn.	Yes	11-B-1, C-2
SWC 11-c3	Soil moisture flow problems and solutions in the Corn Belt region.	Urbana, Ill.	Yes	11-A-4
SWC 11-d1	Principles affecting soil structure stability and its effect on aeration intake, transmission, and storage of water on irrigated lands in the Northern Plains.	Ft. Collins, Colo. Grand Junction, Colo.	Yes	11-A-4
SWC 11-e1	Understanding and improving soil-plant-atmospheric relationships for more efficient utilization of water.	Big Spring, Tex. Bushland, Tex. Weslaco, Tex. Temple-Riesel, Tex.	Yes	11-A-4, B-3, C-1
SWC 11-13(g1)	Physical processes affecting soil water and their relationship to physiological functioning of plants.	Davis, Calif. Brawley, Calif. Riverside, Calif.	Yes	11-A-2, 3, 4, C-1
SWC 11-gF1	Physical properties and kinetics of change of the physical properties of water in soil-water systems.	Riverside, Calif.	Yes	11-A-1
SWC 11-gG1	Uptake and disposal of water by plants in an arid climate.	Tempe, Ariz.	Yes	11-B-2

*Request for extension of project to January 1967 approved June 16, 1965.
**Request for discontinuance without completion approved July 23, 1964.
***Request for discontinuance due to completion approved July 23, 1964.

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SWC 12	Nutrition of animals as affected by properties and characteristics of soils and plants.			
SWC 12-aA1	Studies of the effects of soil and geological conditions on the composition of forages and other crops in relation to nutritional troubles in animals.	Ithaca, N. Y.	Yes	12-C-1,2,3
SWC 12-aA2	Effect of environment, soil type, and soil management on the nutritive quality of crops as measured by animal growth, health, and reproduction.	Ithaca, N. Y.	Yes	12-C-1, 4
SWC 12-aA3 (c)	Micronutrient elements of soils and plants in relation to certain endemic nutritional diseases of animals.	Ithaca, N. Y. Corvallis, Ore.	Yes	12-B-1, 2 C-1
SWC 12-aA4	The role of mineral elements, enzymes, nucleic acids, and other factors in the biosynthesis of proteins.	Ithaca, N. Y.	Yes	12-A-1
SWC 12-aA5	Chemical reactions of micronutrient cations with clay minerals and plant extracts.	Ithaca, N. Y.	Yes	12-D-1
SWC 12-aA6	Toxicities in food and forage plants with particular reference to nitrates and certain mineral elements.	Ithaca, N. Y.	No	
SWC 12-aA7	Effect of plant nutrients and other mineral elements on the amino acid and protein content of food and forage plants.	Ithaca, N. Y.	Yes	12-A-2
SWC 12-aA8	The role of mineral elements in the formation of the organic matrix of bone.	Ithaca, N. Y.	No	

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SWC 13	Fertilizer investigations: Resources, production, and improvement.			
SWC 13-aC1	Consumption of commerical fertilizers in the United States.	Beltsville, Md.	Yes	13-E
SWC 13-aC2	Sources and trends in the production and use of fertilizers and plant nutrients.	Beltsville, Md.	No	
SWC 13-aC3	Fertilizer resources and development in foreign countries.	Beltsville, Md.	No	
SWC 13-4(aC4) (Rev)	Standardization of specifications and test procedures for marketed fertilizer, liming materials, and other soil amendments.	Beltsville, Md.	Yes	13-C
SWC 13-5(aC5) (Rev)	Preparation of special fertilizers (including radioactive material) for experimental use.	Beltsville, Md.	No	
SWC 13-aC6	Effect of physical properties of nutrient materials on the granulation of fertilizer mixtures.	Beltsville, Md.	Yes	13-B
SWC 13-aC7 (Rev) 1/	Fertilizer as a vehicle for soil applications of growth regulators, nematocides, nitrification inhibitors, and herbicides and other agricultural chemicals.	Beltsville, Md.	No	
SWC 13-aC8	Suitability of nitrogen materials for fertilizer use.	Beltsville, Md.	Yes	13-A
SWC 13-aC9	Separation of nitrogen components of fertilizers.	Beltsville, Md.	Yes	13-A
SWC 13-aC10	Inhibitors of urea hydrolysis.	Beltsville, Md.	No	
SWC 13-aC11	Physical characterization of phosphatic fertilizer materials.	Beltsville, Md.	Yes	13-A
SWC 13-aC12	Nutritive value of water-insoluble phosphates in multinutrient fertilizers.	Beltsville, Md.	No	
SWC 13-13 (aC13) 2/	Chemical composition and physical characteristics of agricultural limestone.	Beltsville, Md.	Yes	13-E
SWC 13-aC14	Utilization of flue dust from cement kilns as a liming material and fertilizer.	Beltsville, Md.	Yes	13-A
SWC 13-aC15	Development and evaluation of primary carriers of zinc for use in crop production.	Beltsville, Md.	Yes	13-A
SWC 13-aC16 3/	Amounts of nitrogen, phosphorus, and potassium applied to economic crops in 1959.	Beltsville, Md.	Yes	13-E
SWC 13-17 (aC17) 4/	Development of procedures for determining aluminum, iron, phosphorus, manganese, and titanium in agricultural liming materials.	Beltsville, Md.	Yes	13-A

1/ Revision approved July 10, 1964.
2/ Discontinued, approved January 17, 1963.
3/ Discontinued, approved November 25, 1963.
4/ Approved April 24, 1963.